CHAPTER 7

WAVE RECORDERS

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INTRODUCTION

Several satisfactory instruments are available for recording the height and period of ocean waves, and new improved gages for this purpose are being designed. The actual procurement of wave data is no longer a major problem, but the present theories interpreting these data and the methods of data analysis leave much to be desired. Definitions of characteristic wave height and wave period are vague, as no specific period of observation is designated for determining these measurements. Analysis techniques and results are inconsistent. Preliminary studies of the statistical distribution of wave heights are encouraging, but no simple method of describing the waves with regard to period has been developed. Current hydrodynamic wave theory is apparently in error, and reexamination of this basic theory in regard to the hydrodynamic attenuation factor should be made.

WAVE HEIGHT AND WAVE PERIOD RECORDERS

To obtain comparable experience in the installation, operation and servicing of the significant wave recorders developed prior to 1947, the Beach Erosion Board (1948) tested simultaneously eight different types of wave gages at Atlantic City, New Jersey during May, 1947. The instruments tested were as follows:

1. Underwater Type
    a. University of California Mark III Shore-wave recorder
    b. Woods Hole Shore-recording Wavemeter
    c. Inverted Echo Sounder
2. Surface Type
    a. Float-operated Recorder
    b. Parallel-wire Gage (large wire type)
    c. Parallel-wire Gage (small wire type)
    d. Step-resistance Gage (series type)
    e. Moving-picture Camera
3. Aerial Type
    a. Stereoscopic Cameras

A summary of these tests with a critical analysis of each gage tested appears in a publication of the Beach Erosion Board (Caldwell, 1948). This publication concludes that,

> "....none of the gages, in the form tested, were satisfactory measuring instruments adapted to a long-term measurement program of surface waves. Both underwater pressure gages were satisfactory for the production of records of bottom pressure changes, but the transfer of these records to water surface fluctuations was unsatisfactory. The echo-sounder was found to give an erroneous record. The parallel-wire gages were not found to be adapted to the study because of structural defects and the fluid nature of the calibration curves. The step-resistance gage met all requirements for a short period, but was found to become sluggish and unreliable in continued use. Stereo or movie camera records, although giving accurate pictures of the sea surface, were not considered adapted to a long-term measurement program because of processing difficulties. It was concluded that the step-resistance type gage held the most promise for development into a satisfactory gage with a minimum expenditure of time and effort."

Accordingly, the existing step-resistance gages were modified and improved by the Beach Erosion Board and two types (series type and parallel type) were developed and are in use today. The development of underwater pressure recorders and improved procedures for analyzing pressure records has been continued by the Scripps Institution of Oceanography, the University of California, Institute of Engineering Research, Berkeley, and Woods Hole Oceanographic Institution. As the Beach Erosion Board (Caldwell, 1948) thoroughly reviews the advantages and disadvantages of the significant recorders developed prior to 1947, the remainder of this discussion will be concerned only with recorders used or developed since 1947.

STEP-RESISTANCE GAGE

The step-resistance gage comprises a series of electrical contact points (modified spark plugs) installed at 0.2 ft. intervals along a sealed pipe. The spark plugs are connected to a resistance circuit housed within the pipe. The gage is attached in a vertical position to a supporting structure, such as a pier, with the bottom below the lowest expected wave trough. As the top of the gage must be above the highest wave crest, 25 ft. normally is allowed for its length.

Power is supplied to the gage through a 115 volt a.c. constant voltage transformer, the primary of which is connected through a timing switch to provide automatic programing. This alternating current, supplied to the gage to prevent polarization, is converted through a selenium bridge rectifier to a proportional d.c. current, which drives the recording unit mechanism. A Brush magnetic pen recorder, which has a high frequency response and is capable of recording the shortest period wave, generally is used.

The values of the resistors connected to the contact points of the gage are adjusted so that a straight-line variation exists between the current and the length of the gage submerged. Therefore a record obtained of the variation of the gage current is also a record of the rise and fall of the sea surface. Such a record includes tide stage as well as wave height. Wind chop and wave form are also included in the record providing the response of the recorder is sufficiently rapid.

Three step-resistance gages are in operation on the Pacific Coast at the present time. Located along the California Coast, the first of these gages was installed in May, 1948 at Huntington Beach; another was installed in July, 1948 at El Segundo, and the third was installed during December, 1949 at Mission Bay. With periodic cleaning at four to six month intervals, these recorders have been in continuous operation. Other gages of the step-resistance type have been installed along the Gulf of Mexico and the Atlantic Coast.

Series type step-resistance gage. In the series type gage, the resistors are connected to form a series circuit with the junctions between resistors tied to the contact points. As the sea rises, it shorts all resistors tied to submerged contact points, causing an increase in current proportional to the number of contacts below the surface.

Due to the relatively high value of the resistors connected between the contact points, the film which receding water leaves on the instrument makes it susceptible to current leakage. For this reason, the series type resistance gage is restricted to measurement in fresh water where current leakage caused by the water film is negligible.

Parallel type step-resistance gage. In the parallel type gage, one end of each resistor is connected to a spark plug, the other end being connected to the gage voltage supply. The sea serves as a current path between the contact points and a ground rod, which is connected to the other side of the voltage source. As the spark plugs are submerged, the resistors are added in parallel. The values of these resistors are so selected that the current flowing in the gage is proportional to the number of contact points submerged.

The accumulation of water film does not affect the operation of this type step gage as the resistance values are small in comparison with the water film resistance. However, as the resistance path between the contact points and the ground

rod must be small in comparison to the resistor value, the parallel type step gage is restricted to measurement in salt water.

PRESSURE TYPE GAGES

Surface waves are often measured by recording the subsurface pressure fluctuations and translating these fluctuations to the surface by means of theoretical relationships. The relationships between surface wave characteristics and recorded pressure variations, and the methods of analyzing these pressure records are discussed below.

To obtain a pressure record, a transducer, which converts water pressure fluctuations into electrical current or voltage signals is used to record the pressure fluctuations. The various types of transducers designed for this purpose utilize inductance bridges, strain gages, thermocouples, potentiometers attached to bellows, coils in magnetic fields, and capacitive bridges. Housed in a waterproof case known as a pressure head, the transducer is placed at some point below the water surface and connected by an electrical cable, often several miles long, to a suitable recording unit located on shore. In general, these pressure type "shore wave recorders" are designed to register pressure variations on a continuous strip chart without distortion of the pressure wave form. The system should, therefore, respond linearly with pressure and have a speed of response sufficient to follow the maximum rate of change of the pressure being recorded. The chart paper is divided into uniform rectilinear, or curvilinear, divisions, and the recording mechanism is usually the direct writing type (ink or hot wire). Operation of the system is made simple as unskilled personnel often attend the shore installation. Automatic programing devices operate the recorder according to prearranged schedules.

As a basis for comparing the various pressure type shore wave recorders, the following outline is presented. (This outline of requirements was made prior to building the Mark IX instrument, designed to incorporate the most desirable features of the pressure-type recorder, which is now under development at the University of California.)

A. Record requirements -- reproduction of subsurface pressure variations without distortion.

   1. Uniform response to all wave periods to be recorded.
   2. Linear response with pressure.
   3. No response to temperature variations.

B. Chart requirements.

   1. Direct writing -- pen or hot wire recorder.
   2. Rectilinear coordinate paper.
   3. A chart paper roll sufficient for 36 hours of continuous recording.
   4. Two-speed chart drive to provide continuous recording with automatic fast speed sampling.

C. Remote recording requirements.

   1. Up to five miles of cable.
   2. Adaptable to radio and telephone telemetering.

D. Power requirements.

   1. 115v. a.c. or 115 v.d.c. power line input.
   2. Capable of emergency battery-operation (dry batteries preferred).

E. Operation requirements.

   1. A simple routine to be performed by unskilled operators.

      a. Mark date on charts at specific times.
      b. Change charts.
      c. Wind clocks regularly.

   2. Completely automatic operation.

a. Automatic program timing of fast and slow chart speeds.
b. Warning devices for replacement of charts and winding of clock.
c. Complete fuse protection.

F. Cost requirements.

1. Low cost of manufacture (use of standard parts whenever possible).
2. Inexpensive and expendable pressure head (the more expensive parts and equipment should be reserved for the shore unit).
3. Simple and inexpensive means of analyzing records and calibrating the equipment.

G. Calibration requirements.

1. Static calibration valid for all records.

a. Calibration independent of wave period (minimum wave period of three seconds).
b. Calibration independent of depth of installation (maximum depth of 100 feet).
c. Calibration independent of temperature of water.
d. Calibration independent of input voltage when power line is used (maximum variation of 95 to 135 volts).

2. Simple calibration equipment -- mercury manometer and source of air pressure.

H. Pressure head requirements.

1. Two-years operation without maintenance (fatigue life of 5 million cycles).
2. Light weight and rugged construction for easy handling.
3. Uniformity of operation regardless of position.
4. Inexpensive and expendable.

Mark III shore-wave recorder -- University of California. The transducer of the Mark III recorder (Chinn, 1949) consists of a potentiometer linked to a bellows system which is acted upon in one direction by the average pressure through a slow leak and in the other direction by dynamic pressure. This pressure head senses the pressure variations due to the waves but does not respond to tide changes. The shore installation comprises a special bridge and electronic power supply and an Esterline-Angus pen recording milliammeter. The advantage of this recorder is that its calibration is linear and independent of wave period and water depth, and that the system can be operated from 36 volt batteries with a total load current of 90 milliamperes. However, there are several disadvantages. The pressure head is heavy, difficult to handle and is easily damaged. The life of the potentiometer is limited to about six-months operation.

Mark V shore-wave recorder -- University of California. The transducer of the Mark V recorder (Isaacs and Wiegel, 1950) comprises a 32 junction thermocouple installed in a gas-filled rubber bellows. The reference junctions are in contact with the sea through the pressure head case while the active junctions are acted upon by the gas. The pressure fluctuations of the sea act upon the bellows producing temperature fluctuations in the gas and generating voltages through the thermocouple. As the average gas temperature adjusts and becomes that of the sea, average pressure and tides are not registered by the gage. The shore installation connected to this pressure head is a Leeds and Northrup recording millivoltimeter. The chief advantage of this system is its inexpensive components. The pressure head is simple in design, inexpensive, rugged and easily handled, and the shore installation consists only of a standard recorder. Chief among the disadvantages of this recording system is the difficulty and expense encountered in calibrating the equipment and analyzing the records. Calibration of the instrument is not independent of wave period, depth of installation, and short period temperature fluctuations. Also disadvantageous is the fact that gradual leakage of moisture into the rubber bellows cuts the life expectancy of the pressure head to an average period of about three months.

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Woods Hole shore recording wave meter -- Woods Hole Oceanographic Institution. The transducer of the Woods Hole Recorder (Klebba, 1949) consists of a coil and magnet arranged so that the total magnetic flux linking of the coil varies as the water pressure fluctuates. This is accomplished by attaching the coil to a bellows which is deflected by the pressure fluctuations. A slow leak applies average pressure to one side of the bellows while the other side is acted upon by the dynamic pressure. Tide changes are not recorded. Recording of the flux linkage of the coil can be made with a General Electric photo-electric recorder, a direct writing servomechanism type recorder, or with the Woods Hole photographic recorder. The latter provides a record that can be used directly with the frequency analyzer developed at that institution.

RECORDERS CURRENTLY UNDER DEVELOPMENT

The Scripps Institution of Oceanography has mentioned in their progress reports the development of a recorder which utilizes strain gages in the transducer and is referred to as the Mark VIII shore wave recorder. Preliminary models have been built and now are undergoing field tests.

The University of California, Berkeley, is developing two additional wave gages; (1) the Mark VI shore wave recorder and (2) the Mark IX shore wave recorder. The Mark VI, still in the laboratory, utilizes strain gages to measure the deflection of a flat plate diaphragm which is acted upon by the water pressure. One side of the plate is sealed at atmospheric pressure so that the gage records total pressure. Electrical balancing will enable cancellation of the static pressure reading; tides will be recorded. The recorder is intended to be very rugged and have a high frequency response necessary to record pressure variations in and near the surf zone. The shore unit of the recorder will be a standard Brush magnetic pen recorder. The Mark IX shore wave recorder is an improved version of the Mark III potentiometer type gage designed to be a general purpose instrument with a long life for permanent installations. The shore recording unit is an Esterline-Angus recording milliameter. Two models of this recorder are now undergoing field tests; one at Elwood, California and the other at Point Arguello, California.

WAVE DIRECTION MEASUREMENT

No reliable instruments have been built to date which will measure wave direction. The Rayleigh disk, which was considered a possible solution to this measurement problem, has been investigated and proven unsatisfactory both from an experimental and theoretical standpoint. A study of the behavior of this disk under the action of two or more wave systems was recently completed by the Beach Erosion Board (Hall, 1950). The conclusions of the Beach Erosion Board (Hall, 1950) were:

> "It appears that the records made under natural conditions confirm as nearly as might be expected the theoretical analysis of the behavior of the disk when acted upon by two sine wave systems.
>
> It also appears from the study that the presence of two or more wave systems, the presence of strong currents other than wave currents such as rip tides, and the uncertainty in analysis of the records proves the Rayleigh Disk to be unreliable as a wave direction indicator."

Wave direction can be determined from aerial photographs providing suitable lighting conditions exist and that the water surface is not confused by local wind chop. Visual observation of the sea from any vantage point will enable an approximate determination of wave direction but again local wind may confuse the surface. Suggested as a possible solution to this problem has been the placement of three pressure recorders in a triangle and timing the arrival of the waves at the various recorders. Difficulty may arise with this method due to the short crestedness of ocean waves. Waves recorded at one corner of the triangle may not be evident, or may be of a different wave form, at another corner of the triangle, making timing of the wave difficult.

ANALYSIS OF WAVE RECORDS

Due to the irregularity of ocean waves in height and period, the definitions of terms employed in describing the waves is very important. The following basic

definitions have been accepted (Folsom, 1949):

1. Wave height is the vertical distance between the crest and the preceding trough.
2. Characteristic wave height is the average height of 30 percent of the highest waves.
3. Wave period is the time interval between the appearance at a fixed point of successive wave crests.
4. Characteristic wave period is the average period for the well-defined series of highest waves observed.
5. Wave direction is the orientation of the line of travel of the largest well-defined waves.

The definitions of characteristic wave height and period are incomplete in that the length of observation is not specified. A minimum period of ten minutes has been suggested by Scripps Institution of Oceanography (Munk, 1944) while a minimum of twenty minutes has been suggested by Folson (1949). Little evidence has been published as to the effect of the observation period but, as in measuring any statistical quantity, the longer the period taken the better should be the results providing conditions remain constant. However, using the longer period would mean greater expense in regard to the amount of chart paper to be used in recording data and the amount of time required for analyzing the records.

Analysis of wave records for wave height. In analyzing the wave records made at various locations along the Pacific Coast during the last several years, the following step-by-step procedure has been used by the University of California, Berkeley:

1. Select a continuous record of about a twenty-minute duration which was made while the recorder was operating at fast speed (three inches per minute) and at approximately the time for which wave information is desired.
2. Determine the total number of waves recorded during the selected interval by:
   a. Measuring the wave period of all well-defined waves in the selected interval of the record and computing an average value.
   b. Computing the total number of waves by dividing the determined average wave period into the total seconds covered by the record interval.
3. Determine the significant wave height by:
   a. Measuring the height of the highest 30 percent of the total number of waves in the selected interval.
   b. Computing the average height of the measured values.
4. Determine the average height of the highest 10 percent of the waves as in step number three.
5. Determine the maximum wave height in the selected twenty-minute period.

Excellent correlations have been made of ratios obtained from wave height data recorded daily at several points along the Pacific Coast and analyzed according to the above procedure (Wiegel, 1949). The ratio of the average height of the highest 10 percent to the average height of the highest 30 percent has been found to be 1.29. This ratio was determined from wave data recorded at Point Arguello, California to be 1.30; at Point Sur, California to be 1.27; and at Heceta Head, Oregon to be 1.30. A substantial number of the daily values of this ratio agreed within 10 percent with the average value derived from readings taken over a fourteen-month period at Point Sur and Heceta Head, and over a three-month period at Point Arguello.

Also from the above data, the average ratio of the maximum wave height to the average wave height of the highest 10 percent was found to be 1.46; while the average ratio of the maximum height to the average height of the highest 30 percent

was found to be 1.87. Again a substantial number of the daily values of these ratios compared favorably, agreeing within 20 percent, with the average value. In a tabulation of wave data taken from two widely separated stations in the Atlantic (Cuttyhunk, Massachusetts, and Bermuda) by Seiwell (1947), a constant of 1.57 was found for the average ratio of the average height of the highest 30 percent to the average height of all waves.

The agreement of daily values to the average values of various ratios discussed above and the agreement among values determined at widely separated stations indicated that a definite statistical distribution of wave heights is generated by a storm.

Evidence to further substantiate this theory is found in the results of a statistical analysis conducted by Putz (1950) at the University of California, Berkeley. Analysis was made of twenty-five wave records selected from various localities and made at various times of the year to obtain good sampling. Putz (1950) found evidence that the statistical frequency distribution of observed wave height in a twenty-minute interval is approximately constant in form and, for a first approximation, requires for its complete description only the determination of a typical height, such as the "significant wave-height." The wave-height distribution of all twenty-five pressure records matched, with reasonable accuracy, a Pearson Type III frequency function with a 0.8 positive skewness and proportionality of the mean and the standard deviations.

Utilizing this mathematical model, Putz (1950) computed values for ratios reported by Wiegel (1949) and Seiwell (1947). The value of maximum wave height determined from the model was taken as the probable maximum wave in two twenty-minute intervals as used by Wiegel (1949) in determining his daily maximum wave height. Excellent agreement was found among these three sources as shown in Table I.

TABLE I

Comparison of Wave Height Ratios
for Various Pressure Recorders
and a Frequency Function

Basis of Calculations	Computed Ratios				Remarks
	$\frac{H_{1/3}}{H_{ave}}$	$\frac{H_{1/10}}{H_{1/3}}$	$\frac{H_{max}}{H_{1/3}}$	$\frac{H_{max}}{H_{1/10}}$	
Point Arguello, California wave recorder		1.30	1.85	1.42	3 months of data
Point Sur, California wave recorder		1.27	1.85	1.46	14 months of data
Heceta Head, Oregon wave recorder		1.30	1.91	1.47	14 months of data
Cuttyhunk, Massachusetts wave recorder	1.57				10 months of data
Bermuda wave recorder	1.57				4 months of data
Average of wave record values	1.57	1.29	1.87	1.46	
Pearson Type III frequency function MODEL	1.57	1.29	1.81	1.41	Model based on 25 selected records

Analysis of wave records for wave period. Analysis of wave records for the characteristic period is accomplished by measuring the average period of the larger, well-defined waves appearing on the record. This is comparable to measuring the characteristic height of the waves by determining the average height of the highest 30 percent of the waves. The characteristic period of the waves does not describe the period-distribution, however, as the characteristic height describes wave-height-distribution. Although wave heights have been found to follow a simple mathematical distribution even though the waves may be arriving from two or more storm areas, wave periods do not follow a simple distribution if more than one generating area exists. Additional information is needed to adequately describe wave periods.

The need for more accurate methods of analyzing wave periods has led to the development of two types of electrical-mechanical analyzers, (1) a frequency analyzer and (2) an auto-correlation function analyzer.

The frequency analyzer measures the presence of the various sinusoidal frequency components in the record and produces a frequency distribution curve. Even though this analysis may give an accurate mathematical representation of the data, the validity of its physical representation has been questioned by Seiwell (1949, 1950). A study of the frequency distribution curves of pressure type wave recorders by the Admiralty Research Laboratory (1947) and later by Munk (1947a, 1947b) indicates that this type analysis is useful in tracking storms and in correlating meteorological and wave data.

The second type of analyzer, which is based on the auto-correlation function, has been investigated at the Marine Physical Laboratory, University of California (Rudnick, 1949) and at the Woods Hole Oceanographic Institution (Klebba, 1949). Although still in the process of development, this method shows promise of more accurately describing the physical characteristics of surface waves than the frequency analyzer.

Analysis of under-water pressure records. The analysis of pressure records for wave period is the same as the analysis of surface wave records. The records differ, however, in that the short period waves are not registered to the same degree as the long period waves by pressure recorders due to the hydrodynamic pressure attenuation of the water. As a result, many of the shorter period waves may not appear on the pressure record.

If the technique of measuring the periods of only the larger, well-defined waves of the record is followed (as described in the above section), the measured period will be approximately the same as would be obtained if the record were made with a surface type gage. For locations on the exposed coast, the short period waves, not recorded by pressure, generally are generated by local wind. Irregular and of small amplitude, these waves are neglected in the analysis of surface records.

In several cases, attempts have been made to utilize the hydrodynamic attenuation of short period waves by installing gages in deep water (about 600 feet) so that only the waves of long periods (the characteristic forerunners of storms) will be recorded. These long period waves are recorded by pressure heads installed in shallow water, but are "lost" in the record of shorter period waves. Installations of this type of instrument have been made, but due to instrument difficulties no satisfactory records have been obtained.

To obtain the surface wave heights from the pressure record, two factors are required; (1) the calibration of the instrument and (2) the pressure response factor relating the subsurface pressure fluctuations to the surface wave. Thus, if

H = wave height at the surface (in feet);

C_i = calibration factor of the instrument (expressed in feet of water pressure variation per chart division);

K = pressure response factor based on the depth of the instrument, the depth of the water and the length (or period) of the wave being recorded;

R_1 = reading of the instrument;

the following equation is used to obtain the surface wave height:

$$H = C_1/K\ (R_1) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The calibration factor for most instruments in use today is a constant independent of wave period and depth of the instrument. The instrument provides a record of the pressure variations at the instrument which is accurate in amplitude and wave form.

The relation of the subsurface pressure fluctuations to the surface wave has been determined theoretically for two dimensional, irrotational motion of an incompressible fluid in a relatively deep channel of constant depth (Folsom, 1947). The response factor K has been shown to be:

$$K = \frac{\cosh 2\pi d/L\ (1 - z/d)}{\cosh 2\pi d/L} \quad \ldots\ldots\ldots\ldots \quad (2a)$$

where

z = depth at which the pressure variation is being measured (in feet),

d = depth of water at the instrument (in feet),

L = length of the surface wave (in feet).

When z = d, the pressure variation is measured at the bottom and equation 2a reduces to:

$$K = \frac{1}{\cosh 2\pi d/L} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2b)$$

Pressure records do not enable the direct measurement of wave length; the wave length must be calculated from the wave period using the following equation:

$$L = \left(\frac{gT^2}{2\pi}\right) \tanh 2\pi d/L \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where T = wave period (in seconds).

Suitable graphs and tables (Wiegel, 1948) are available for the solution of these equations. Graphs have been prepared which enable the response factor (K) to be determined if the water depth (d), instrument depth (z) and wave period (T) are known. Two errors arise when the above equations are used to determine the response factor (K) for ocean waves; (1) an average or characteristic period must be used in the equation while the actual wave period is continuously varying and individual waves are not sinusoidal in form, (2) wave heights computed from these equations have been shown by several observers to be from six to twenty-five percent too low.

Considering the first of these two errors, greater accuracy probably could be attained if the pressure response factor (K) were determined for each wave and the equivalent surface wave were individually computed. This procedure might be feasible from a practical standpoint if the statistical distribution of wave height and wave period could be established so that fewer waves need be analyzed to completely describe the state of the waves. (See the above section on "Analysis of wave records for wave height").

The second of these two errors emphasizes the need to reconsider the basic theory which does not agree with experiment. Every observer who has simultaneously measured the surface waves and the subsurface pressure fluctuations has found the theoretical response factor determined from equation 2a to be too small. Ten random measurements made at the Waterways Experiment Station (Folsom, 1947) indicated an average correction of 1.07 should be applied to equation 1. Seventeen laboratory measurements at the University of California, Berkeley, indicated an average correction of 1.10 (1949). Field data reported by the Woods Hole Oceanographic Institute (Admirality Research Laboratory, 1947; Seiwell, 1947) indicated a correction factor in excess of 1.20 while the three sets of field data obtained at the University of California (Folsom, 1946) indicated values of 1.06, 1.08, and 1.18.

EXISTING WAVE DATA

A summary of the periods of time for which records are known to exist at various localities along the Pacific Coast of the United States is presented below. This information may prove of value to engineers engaged in the design of structures at certain localities where wave data, however meager, will be of assistance.

For the past few years a number of wave recorders have been installed and operated along the Pacific Coast more or less continuously by various institutions and government agencies. The University of California, Berkeley, in cooperation with the U.S. Navy, instituted a program of wave recording at several points along the Pacific Coast in 1947. Charts from these records have been analyzed for the "significant" wave height and the wave period. Wave direction also was determined in some instances from synoptic weather charts by the wave forecasting method described in Chapter 8. These various data have been summarized in tabular form and distributed to various individuals, commercial concerns, and government agencies that were interested in this type of information (Isaacs and Schorr, 1947). In a limited number of cases summaries of wave data have been published (Wiegel, 1949; Wiegel and Kimberley, 1950).

Table II shows the periods for which wave data are available for the various recorders located as shown in Fig. 1. Inquiries regarding the data from any particular recorder should be directed to the address listed in footnotes to Table II. In addition to the records from recorders on the Pacific Coast, it is of interest to note that the University has recorded waves at Apra Harbor, Guam, M.I. for the period January 19 through July 5, 1949, and at Pokai Bay, Oahu, T.H. from October 20 to October 27, 1949.

In addition to statistical wave data obtained from recorders, a certain amount of data have been assembled by the hindcasting procedure described by R.S. Arthur in Chapter 8. The most comprehensive compilation in this field was a study by the Scripps Institution of Oceanography in cooperation with the U.S. Engineers Office, Los Angeles, on wave conditions at five open sea localities along the California Coast for the three-year period 1936 to 1938, inclusive (Scripps Institution of Oceanography, 1947). Hindcasts, for shorter periods of time, have been made for various localities along the Pacific Coast by the Department of Engineering, Berkeley. A summary of the localities and periods for which hindcast data are available is given in Table III for both the Scripps and Berkeley studies.

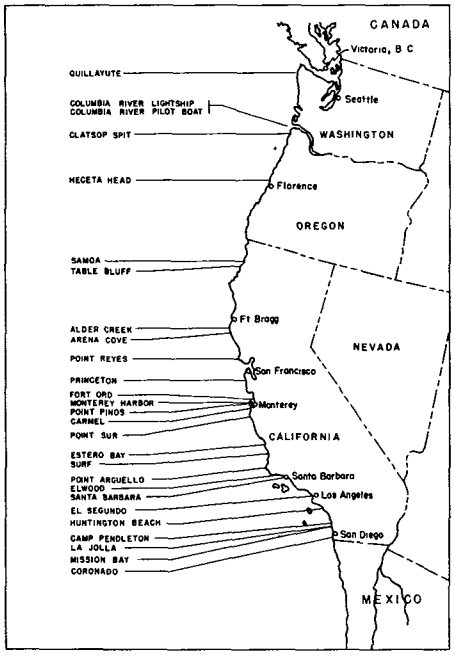

Fig. 1. Pacific Coast Wave Recording Stations.

TABLE II

Pacific Coast Wave Recorders

Location	Type	Installed	Abandoned	Remarks
University of California, Berkeley*				
Quillayute, Washington	UC Mk. V	10-27-48	11- 3-48	Cable destroyed in storm.
Columbia River Lightship	Visual	8- 1-33	8-31-36	Observations made in cooperation with the Corps of Engineers and the Coast Guard.
Columbia River Pilot Boat, Oregon	Visual	10- 9-49	11-29-49	Not observed on Nov. 24 and 25, 1949.
Clatsop Spit, Oregon	UC Mk. V	5- 8-50	6-14-50	Inoperative on several occasions for 2 or 3 days.
Heceta Head, Oregon	UC Mk. III	5-16-47	11-23-48	Not operating 4-14-48 to 11-6-48.
Samoa, California	Sighting bar	8- 5-44	2-24-45	Observations also made during Dec. 1945 and January 1946.
Table Bluff, California	Sighting bar & photos	2-26-45	1-29-46	Not observed on several occasions.
Alder Creek, California	Sighting bar	8-26-44	2-16-45	Observations approximately four miles north of Pt. Arena.
Arena Cove, California	Sighting bar	10- 3-44	12-31-44	
Point Reyes, California	Sighting bar	7- 7-44	11-26-45	
Princeton, California	UC Mk. II	10- 3-45	10-26-45	Sighting bar observations also made at Miramar Hotel during parts of July and October 1945.
Fort Ord, California	Sighting bar	11- 1-44	8-31-45	Mark V recordings were taken on several occasions in March 1950.
Monterey Harbor, California	UC Mk. III	5-15-46	8- 7-46	Recorder installed on Municipal Pier inoperative on several occasions.
Point Pinos, California	UC Mk. III	3-21-50	Active	Recorder inoperative on several occasions for 2 or 3 days.
Carmel, California	UC Mk. III	9- 1-46	10-18-46	Not operating 9-6-46 to 10-10-46.
Point Sur, California	UC Mk. III	4-25-47	Active	Inoperative 9-14-47 to 10-16-47 and 7-12-48 to 9-21-48.
Estero Bay, California	Various	12- 4-44	8-31-45	Observations made by sighting bar, recorders and from photographs.
Surf, California	Sighting bar	1-29-45	3-12-45	
Point Arguello, California	UC Mk. III	6- 6-48	Active	Inoperative 10-11-48 to 3-16-49, 4-16-49 to 8-9-49 and 3-6-50 to date.
Elwood, California	UC Mk. IX	8-10-50	Active	
Santa Barbara, California	UC Mk. V	4-20-50	Active	
Camp Pendleton, California	UC Mk. V	3- 7-49	Active	Not operating 3-21-49 to 5-5-49 and 1-16-50 to 7-1-50.
La Jolla, California	Sighting bar	6-22-44	9- 4-45	Not observed during the period 7-25-44 to 11-30-44.
Coronado, California	Sighting bar	11-30-44	9- 7-45	Not observed during the period 3-9-45 to 3-24-45.
Scripps Institution of Oceanography**				
La Jolla, California	Various	-	-	Exact periods of operation are unknown.
Beach Erosion Board***				
El Segundo, California	B.E.B.	7-26-48	Active	Not operating 3-7-49 to 3-25-49 and 6-17-49 to 6-31-49.
Huntington Beach, Calif.	B.E.B.	5-29-48	Active	Not operating 1-4-50 to 4-27-50.
Mission Bay, California	B.E.B.	12-13-49	Active	First 3 months of record are of questionable value.

For information on data from the various recorders, inquiries should be directed to:

* Director, Institute of Engineering Research, University of California, Berkeley 4, California.

** Director, Scripps Institution of Oceanography, La Jolla, California.

*** President, Beach Erosion Board, Corps of Engineers, 5201 Little Falls Road, N. W., Washington 16, D.C.

TABLE III

Statistical Wave Data Compiled by the Hindcasting Method

Location	Period of Hindcast
University of California, Berkeley	
Columbia River Pilot Boat	10- 7-49 to 12-23-49
Clatsop Spit, Oregon	2- 5-50 to 4- 1-50
	5- 1-50 to 6-16-50
Heceta Head, Oregon	4-25-47 to 1- 1-48
Humboldt Bay Entrance, California	8- 5-44 to 8-31-45
	11-19-45 to 7-31-46
Table Bluff, California	12- 3-45 to 1-31-46
	1- 4-45 to 8-31-45
Pt. Arena, California	10- 1-44 to 2-30-45
Pt. Reyes, California	7- 7-44 to 9-30-44
	10- 1-44 to 8-31-45
Fort Ord, California	4- 1-45 to 9-29-45
	1- 3-45 to 3-31-45
	3-20-46 to 7-31-46
	2- 5-50 to 4- 1-50
	5- 1-50 to 6-16-50
Point Pinos, California	2- 5-50 to 4- 1-50
	5- 1-50 to 6-16-50
Carmel, California	4-24-46 to 8- 3-46
Pt. Sur, California	4-25-47 to 1- 1-48
	2- 5-50 to 4- 1-50
	5- 1-50 to 6-16-50
Estero Bay, California	4- 1-45 to 9-29-45
	10- 5-45 to 10-22-45
	4-12-44 to 4-31-44
	5-12-44 to 3-31-45
Pt. Arguello, California	7-28-45 to 9-29-45
	5-31-50 to present
La Jolla, California	6-22-44 to 8-13-44
Coronado, California	4- 1-45 to 8-31-45
	11-30-44 to 3-31-45
Scripps Institution of Oceanography, La Jolla	
Lat. 42.5° N Long. 125.0° W	1936 - 1938 Inclusive
Lat. 40° N Long. 125.0° W	" " "
Lat. 37.5° N Long. 123° W	" " "
Lat. 35.0° N Long. 121° W	" " "
Lat. 33.0° N Long. 120.0° W	" " "

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