THE WAVEMETER: A LAND-BASED SYSTEM FOR MEASURING NEARSHORE OCEAN WAVES

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The Wavemeter: A Land-based System for Measuring Nearshore Ocean Waves

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This paper describes a method for measuring nearshore ocean wave characteristics with a land-based, long-period vertical seismometer. The wavemeter system has proven to be highly reliable and produces continuous wave observations at low cost. It is now operational at six Coast Guard stations along the Oregon and Washington coasts; data from the stations are relayed via teletype to the National Weather Service for use in making and verifying wave forecasts.

INTRODUCTION

For the past five years, we have been working to improve nearshore ocean wave forecasts for operational use along the Oregon coast. A major problem in such work is the measurement of wave height and period for forecast verification.

As a backup to conventional pressure sensors, which proved unreliable at our location, and visual observations, which can only be made in daylight and under favorable weather conditions, we decided to investigate the utility of measurements made with a seismometer, based on the assumption that the theory of Longuet-Higgins (1950) could be applied to our situation and recognizing that others (Darbyshire, 1950) had found certain correlations long ago.

The theory predicts that ocean waves traversing a sloping beach will be reflected partially, that the interaction of incident and reflected waves will result in the formation of standing waves, and that the standing waves will produce a pressure field on the ocean bottom which will generate seismic waves propagating in the horizontal plane which can be detected at some distance from their source.

In deep ocean areas (depths of kilometers) the theory considers both the compressibility of water and resonance effects between the ocean waves, the water column and the reflector represented by the sea floor; for shallow water, however, compressibility effects are negligible and resonance cannot occur. In this case, Longuet-Higgins shows that:

$$\bar{p} \propto a^2 w^2 \cos 2wt \qquad (1)$$

where: $\bar{p}$ is the mean pressure on the sea floor
a is the wave amplitude
w is $2\pi/P$, where P is the wave period

We assume that the amplitude of the seismic motion is linearly related to the pressure which causes it, and expect the motion to have one-half the period of the ocean wave. Further theoretical work (Hasselmann, 1963) suggests that both the fundamental ocean wave period and the half-period component should be present, the fundamental component being much the lesser of the two. This has been confirmed for pure swell conditions by Haubrich et al (1963).

With this theory as our basis, we installed a seismometer at the Oregon State University Marine Science Center, Newport, Oregon (about 2 km from the shore) in May 1971. Correlation tests at this location confirmed the utility of the Longuet-Higgins theory, and subsequent tests at other locations showed that seismometer installations, together with simple linearizing electronics, can produce useful estimates of nearshore wave height and period.

The first operational installation was made at the Yaquina Bay Coast Guard Station, Newport, Oregon, in October 1973, and the last of the six stations planned for the observing network along the Oregon and Washington coasts was installed in October 1975.

INSTRUMENTATION

The seismometer is a portable commercial unit (Teledyne-Geotech Model SL-210) designed for geophysical surveys (Figure 1). It has an adjustable natural period of 10-30 seconds and is furnished in an hermetically-sealed cast aluminum case. An electrical signal proportional to the vertical velocity of the case is produced by a moving-coil transducer; the transducer is terminated with a damping resistor by means of which an approximately critically-damped spring-mass system response with a natural period of about 18 seconds can be realized. The seismometer signal (~± 2.5 mv. max.) may be recorded directly on a strip-chart recorder if pre-filtered for ambient seismic noise by a low-pass filter with a break point at ~0.7 Hz.

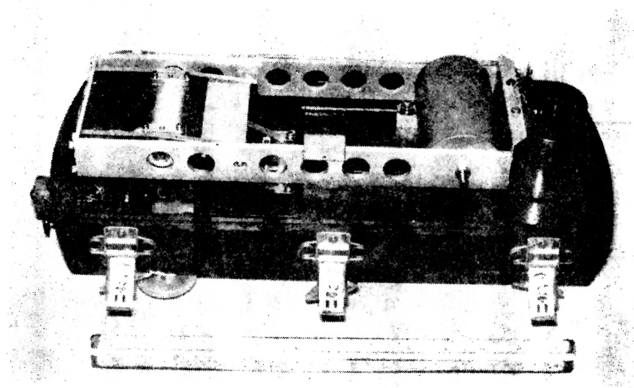

Fig. 1. Wave sensing vertical seismometer, cover removed.

For operational use, the linearizer shown in Figure 2 and having the simplified block diagram and circuit diagram of Figure 3 produces wave information directly. An active filter with a $1/w^3$ response between 0.1 and 0.4 Hz (equivalent to ocean wave periods of 20-5 seconds) removes the wave period (w^2) dependence in Eq. 1 and compensates for the w dependence of the velocity transducer as well. The scale graduations on the analog meter output remove the a^2 dependence in Eq. 1, and so the meter can be read directly in feet of wave height. Full-scale on the meter is 20 feet; it can be changed by adjustment of the linearizer gain.

The remainder of the electronics provides required signal pre-filtering, gain, and scaling of the

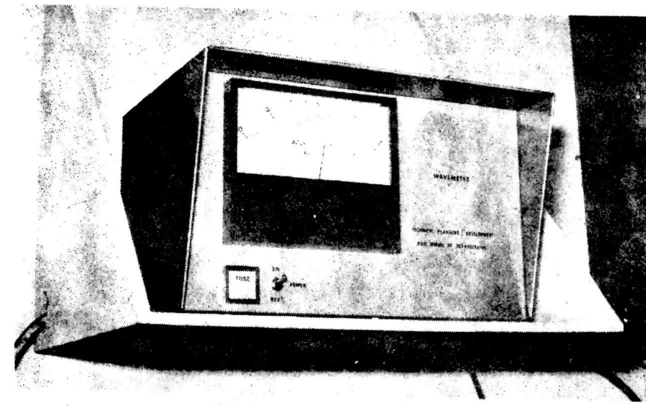

Fig. 2. Seismometer signal linearizer.

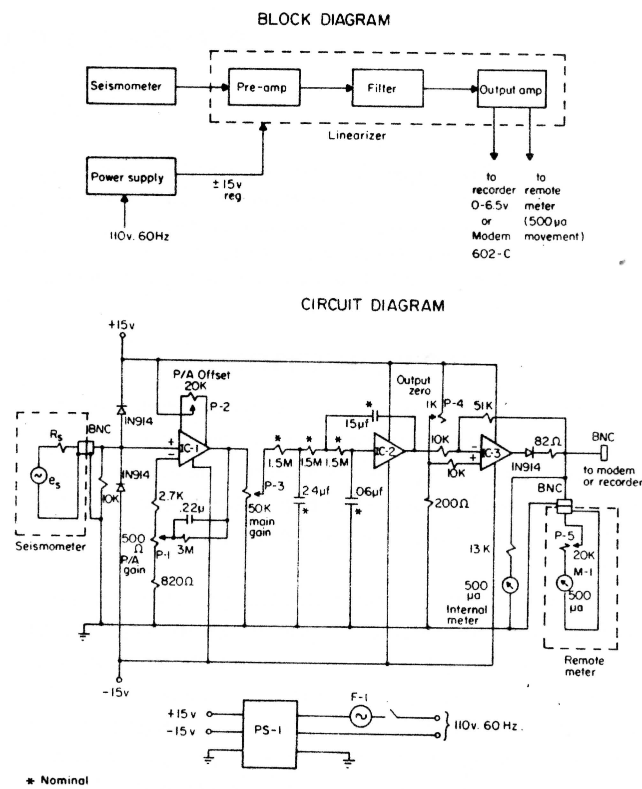

Fig. 3. Block diagram and circuit diagram of linearizer.

output signal for meter indication, recording and interfacing with a standard Bell System Model 602-C data set for remoting over a telephone line to distant users. The linearizer can drive a remote analog display meter up to one mile away over a normal telephone pair without the data set, and this mode of operation is employed at several Coast Guard Stations.

CALIBRATION

If one records the output of the seismometer on a strip-chart and measures the peak-to-peak deflections and consurrent zero-crossing periods, the results can be used to arrive at an empirical calibration for the particular seismometer location. For this purpose, Eq. 1 may be recast as:

$$d = \frac{K H^2}{P^3} \qquad (2)$$

where: d is the recorder p-p deflection in per cent of full-scale

K is a constant

H is wave height, peak to trough, in feet (the unit of current Coast Guard observations)

P is seismic signal period, in seconds; it has exponent 3 because of the velocity transducer in the seismometer.

If H is determined simultaneously by other wave measurement techniques, then K can be evaluated. By repeating the process for many observations over the full range of wave heights and periods, the accuracy and repeatability of seismic measurements in relation to other techniques can be determined. Figure 4 shows sections from three records of the pre-filtered seismometer signal.

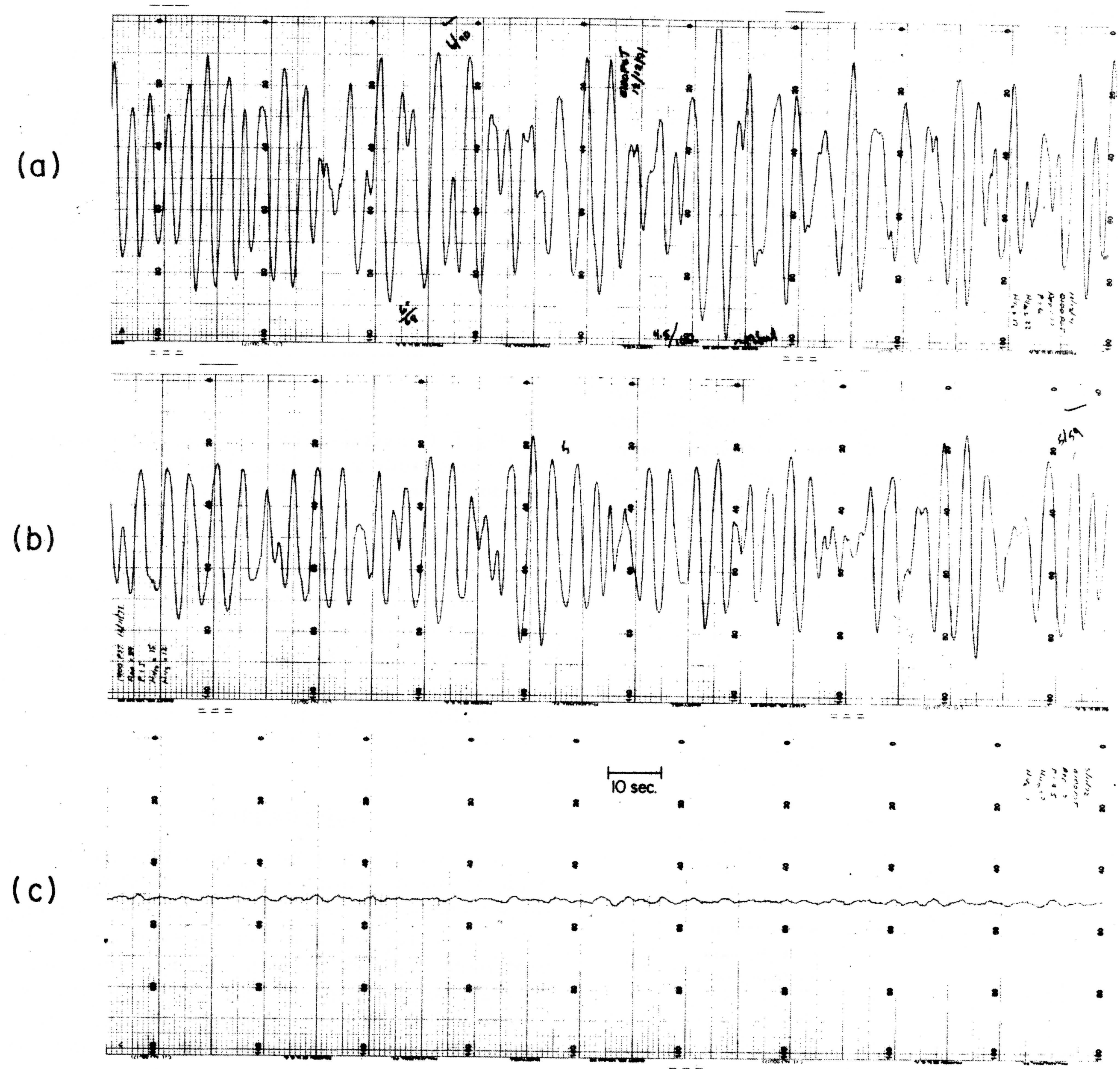

Fig. 4. Typical seismometer signals, Newport, Oregon.
a) $H_{1/10}$ = 22 ft., P = 12 sec., 17 Nov 1971)
b) $H_{1/10}$ = 15 ft., P = 10 sec., 11 Dec 1971.
c) $H_{1/10}$ = 2 ft., P = 10 sec., 11 May 1972.

Once system gain is set to match observations, users are asked to log visual and wavemeter observations for an additional month to assure system stability and to assist observer training. The station then becomes operational. Coast Guard personnel report wave height and period in the standard teletype message format according to a fixed schedule and log the observation on a NOAA marine weather station form (OMB 72-5A).

Observer training requires an hour; it involves certain ground rules for taking readings from the analog display meter, and use of a stopwatch to time zero-crossings of the meter needle to determine seismic wave period. The observer multiplys the seismic period by 2 to arrive at ocean wave period; because of the density of scale markings on the meter, periods are not accurate for wave heights less than about 5 feet, but neither are they operationally significant.

We provide a maintenance manual to the electronic technician at each station in case repair becomes necessary; so far, only one station has had a problem, and that was caused by a transient signal from a nearby lightning strike to ground. Even though system reliability has been demonstrated, we continue to visit each station periodically to check seismometer stability, to make spot checks on calibration and to train new observers.

In routine operation, the system has three idiosyncracies of which an observer must be aware:

1. The seismometer detects earthquakes, and the signal generally appears on the output meter as full-scale deflections with a period of about 18 seconds (the natural period of the seismometer). Observers easily learn to spot an earthquake signal by the abrupt change in meter reading amplitude and the long period of the meter needle zero-crossings (seismic signal periods due to waves are less than 10 seconds). Earthquake signals may last from about an hour to several hours; during these intervals, which occur infrequently at our stations, the wavemeter cannot be used for wave observations.

2. Wavemeter readings will also be high if incoming waves encounter a strong offshore wind. Apparently the offshore wind creates an artificial reflected wave which interacts with incoming waves to produce a higher than normal seismic signal, as noted by Tabulevich (1963). At our stations, this situation has occurred occasionally with east winds of 20 knots or greater which have lasted for at least 12 hours, and can result in up to twice the correct wave height indication; the wave period deduced from meter zero-crossings seems not to be affected.

3. At the Cape Disappointment, Washington, station, the large outflow from the Columbia River interacts with incoming waves to increase their height on the bar around the time of maximum ebb current. The seismometer does not detect the increase, since it senses the effect of offshore waves. A correction table is used at this station to adjust wavemeter readings for the ebb tide effect as a function of the maximum ebb current predicted in the National Ocean Survey's standard tidal current tables for this location. Ebb corrections are not considered necessary for operational purposes at our other stations, and none of the stations requires correction for flood or slack tide conditions.

APPLICATIONS

Wavemeter installations are now operational at the six Coast Guard stations shown in Figure 7.

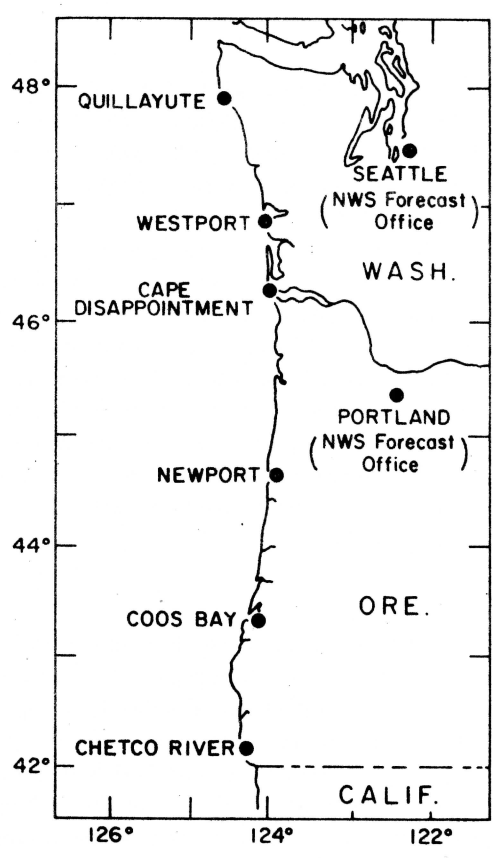

Fig. 7. Location of wavemeter installations at Coast Guard stations.

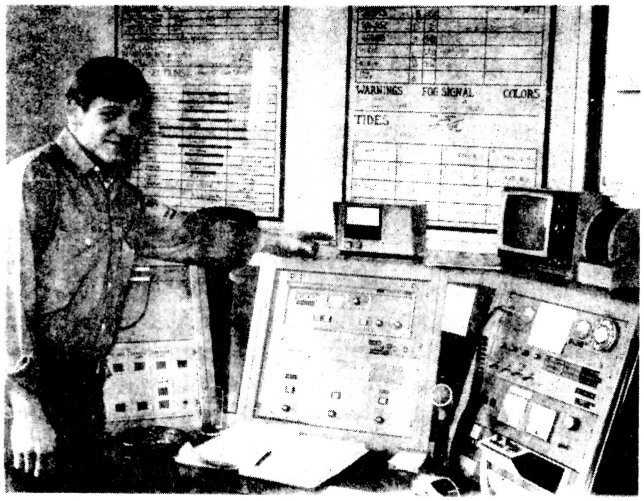

Fig. 8. Wavemeter installation—Westport (Washington) Coast Guard station.

Wave reports are sent via teletype to National Weather Service forecast offices at Portland, Oregon, and Seattle, Washington. It appears that the present network is sufficient to support Coast Guard and NWS operations along the Oregon-Washington coast. Figure 8 shows a typical installation.

At Westport, Washington, the local cable television company has its weather information panel in the Coast Guard station. A video camera mechanically scans analog meters displaying values of weather parameters, and we have added a meter display of wave height for the use of commercial and recreational boating interests. Because the camera scans the meter for only a few seconds, a quasi-static needle indication is required; we have added a peak-reading circuit in the wavemeter to satisfy this requirement, so wave period cannot be estimated from the display. Similar displays may be added at other locations if user response is favorable and signal remoting, with its attendant costs, can be circumvented.

For a 30-day period in February 1975, the wavemeter signal from Newport was remoted to the NWS forecast office in Portland, Oregon, to test its value to wave forecasters. Forcaster response was highly favorable, and NWS is now considering both a permanent remoting from Newport and interrogation capability to the other wavemeter stations from the Portland and/or Seattle forecast offices.

The National Weather Service is developing a computer-controlled automatic data acquisition system for surface stations, called DARDC, and has asked us to consider interfacing the wavemeter output with the system. This can be done in principle by adding: (1) a square-root module after a peak reading circuit in the existing linearizer (for wave height), and (2) a zero-crossing counter producing a BCD output (for wave period), to mate with two existing input channels of the DARDC remote station module.

Ocean waves propagating from a distant fetch area disperse; those with longer periods travel faster than those with shorter periods, and in theory, detection of long-period waves can aid the forecaster in determining the arrival time and amplitude of the highest waves from the fetch. For the past year, we have been testing an extension of the wavemeter electronics which emphasizes the amplitude of the long-period waves (12-24 seconds) and measures their period. Our results to date indicate that, by tracking wave height and period (from the usual wavemeter output) and the period only of the long-period waves (from further filtering of the wavemeter output), characteristic trends can be established which may be of substantial value to forecasters when the group velocity of approaching waves exceeds the shoreward velocity of fetch movement. The ultimate result of these tests will be reported in another paper.

ECONOMICS

We estimate that the wavemeter system presently could be marketed by a commercial manufacturer for $5,000-$6,000 per unit. With reasonable attention to instructions in the maintenance manual, the buyer can install the system at his site for direct reading. Remoted systems would add data set and line leasing costs, and a user might also opt for various forms of output recording at additional expense.

The seismometer requires no maintenance, but in case of physical damage should be returned to the manufacturer for repair. The linearizer electronics appear to be reliable and stable; our first unit now has 3 years of continuous operation without failure or servicing, and other units in the field have been operating reliably. A spare parts kit containing the active elements of the linearizer would cost about $100. Continuing costs consist only of electric power charges for the heater (to stabilize seismometer temperature) and linearizer electronics; they would generally total less than $50 per year.

ACKNOWLEDGEMENTS

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