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It now appears technologically and economically feasible to obtain reliable and reasonably accurate all-weather wave observations for critical areas (e. g. , harbor entrances) along the Pacific Northwest coast of the U. S. in winter, through the use of seismic sensors. In the past it has been found that the traditional sea-based sensors (e. g., pressure transducers on the sea floor) could not cope with the late fall, winter, and early spring wave and surf conditions. During these periods, either the bottom sensor was covered over through seasonal shifting of sand or the cables were broken as a result of turbulent surf conditions. With such systems, outage time could be large and replacement costs high. In the search for a more reliable and less expensive way of obtaining wave information, the use of a land-based seismometer to infer wave height and period was considered; and, at least at those sites so far tested, it appears that this method is quite effective.

In retrospect, this sensing method was a by-product of earlier research efforts. From 1969 to 1972 Oregon State University was involved in the development of a technique for forecasting wave and surf conditions over the treacherous Columbia River Bar, under a NOAA-National Weather Service contract. From 1971 on, the base for these studies was broadened through NOAA-Sea Grant support to develop a sea and surf forecasting capability for the Pacific Northwest coastal zone of the U. S. Earlier attempts to verify and improve wave forecasting techniques over the more turbulent regions, such as this, relied heavily on hindcast data. In other words, forecasts relied on preliminary analyses and prognostic inputs and the hindcasted verifications on finalized analyses. However, the fallacy of this rather universal approach to verification is that it assumed the forecast technique to be perfect if the input was perfect. Improving the basic forecasting system required routine wave measurements for verifications. All attempts to instrument sites along the Oregon coast with traditional bottom sensors ended in failure. (The U. S. Army Corps of Engineers attempted to instrument the mouth of the Umpqua River and the University attempted to instrument the mouth of the Yaquina River.) This resulted in a search for a less vulnerable and more reliable method of obtaining wave measurements.

It was decided to investigate the utility of measurements made with a long-period vertical seismometer, based on the assumption that the theory of Longuet-Higgins (1950) could be applied in this situation, and realizing that others (Darbyshire, 1950) had found certain correlations long ago. Theory predicts that ocean waves impinging on a sloping beach will experience some reflection, that the interaction of incident and reflected ocean waves will result in the formation of standing waves, and the standing waves will produce a pressure field on the ocean bottom which in turn will generate seismic waves propagating in the horizontal plane. It is assumed that the amplitude of the seismic motion is linearly related to the pressure field, and it is expected to have twice the frequency of the ocean wave which generated it.

Based on the discussed theoretical considerations, a long-period vertical seismometer with a self-timed recorder was installed at the Marine Science Center, Newport, Ore., in May 1971. The initial system was automatically programmed to produce 12-min records on a strip chart at 6-hr intervals. For calibration tests on the system, visual observations were made against a 4-m-high buoy located in 20 m of water about 2 km offshore (fig. 5). An observer located on a hill about 40 m above sea level and 3 km from the buoy, observed the buoy through binoculars; and by knowing the height of various features of the buoy, estimated the height and period of the highest 10 percent of the waves passing the buoy. On other occasions, test wave data were also obtained from a portable bottom-mounted pressure sensor system and a sensitive fathometer operated from the University ship PAIUTE near the buoy. Using 1971-72 data, the regression of visually observed wave heights (H_o) on seismometer inferred wave heights (H_s) was found to be $H_o = 1.07\ H_s - 0.87$ (ft) with a correlation coefficient of 0.87 and a standard error of estimate of 1.61 ft.

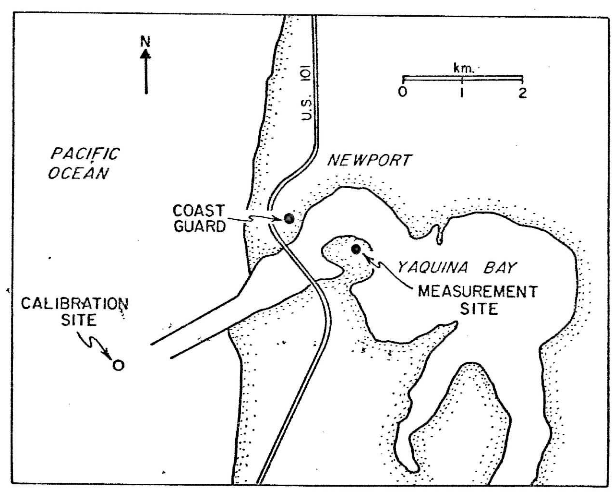


Figure 5.---Location of calibration site.

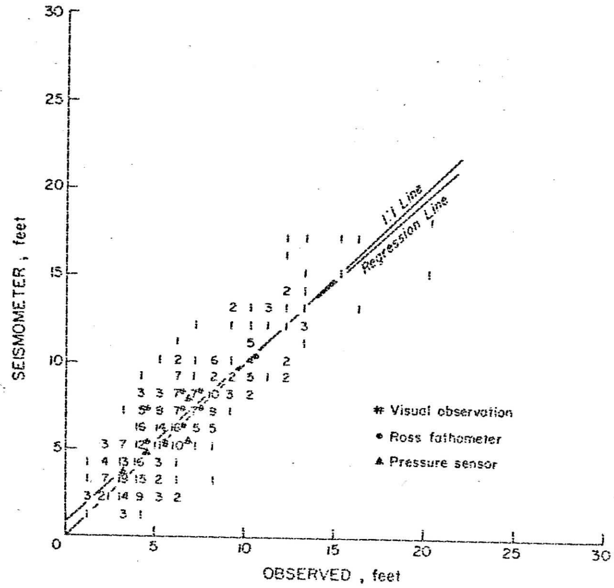


Figure 6.--Relationship between observed wave heights and seismometer-inferred wave heights.

Figure 6 is a scatter plot of the data. Data for 1973 and 1974 confirm this correlation. A similar comparison of ocean wave periods confirmed the 2:1 relationship discussed earlier. After calibration, a meter was designed from which wave height and period could be obtained (fig. 7).

The 2 yr of data from the Yaquina River mouth, one winter's data from near the Columbia River mouth, and recent data from the mouth of the Umpqua River indicate that wave height and period can be inferred from the output of a properly located vertical seismometer. If an earthquake occurs during the recording period, it shows up on the recorder chart as extremely large amplitude fluctuations with a period of about 18 sec, which is much longer than the half-periods of waves (2 - 9 sec) as sensed by this system. Hence, it is easy to screen out disturbances of this nature.

The advantages of this wave sensing system are summarized as follows:

1. It has high reliability (outage negligible) and is sufficiently accurate for operational use.
2. Its utility is not limited during extremes in sea or weather conditions.
3. Operational characteristics do not appear to be affected by the sizeable tidal variations along the Oregon coast.

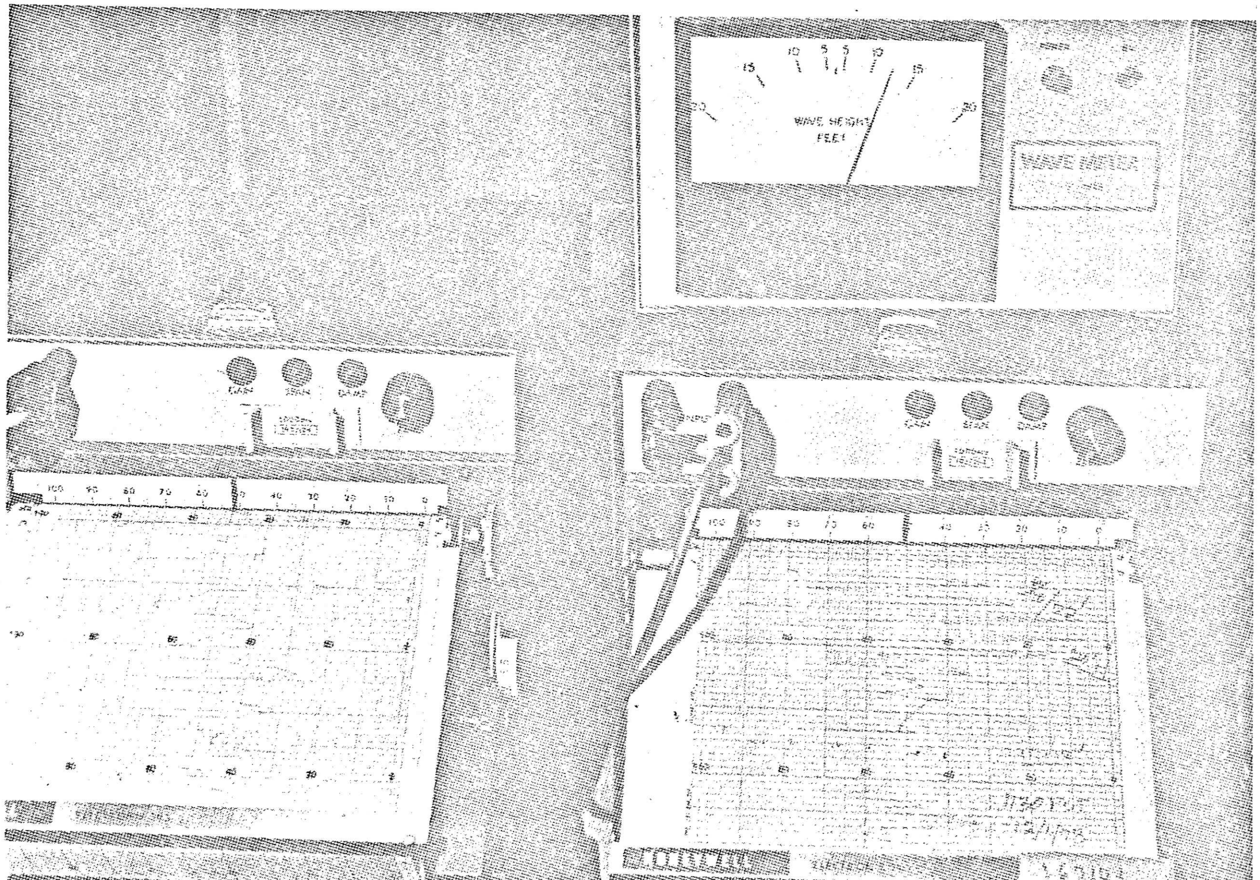
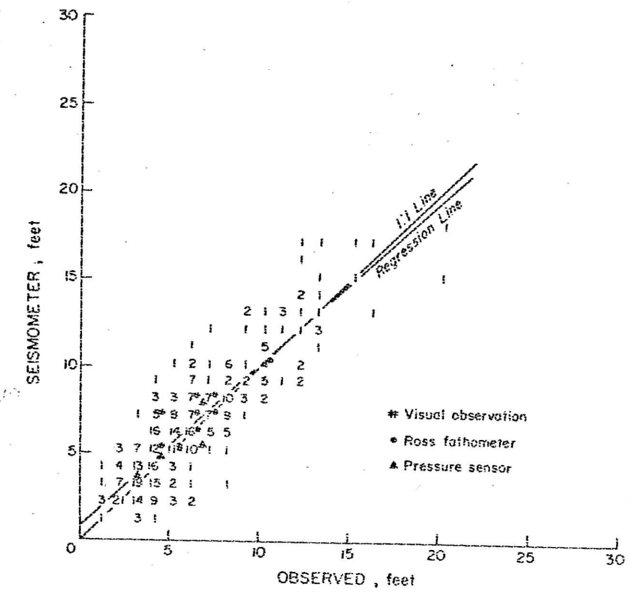


Figure 7.--The wave meter registering a 12.5-ft wave.



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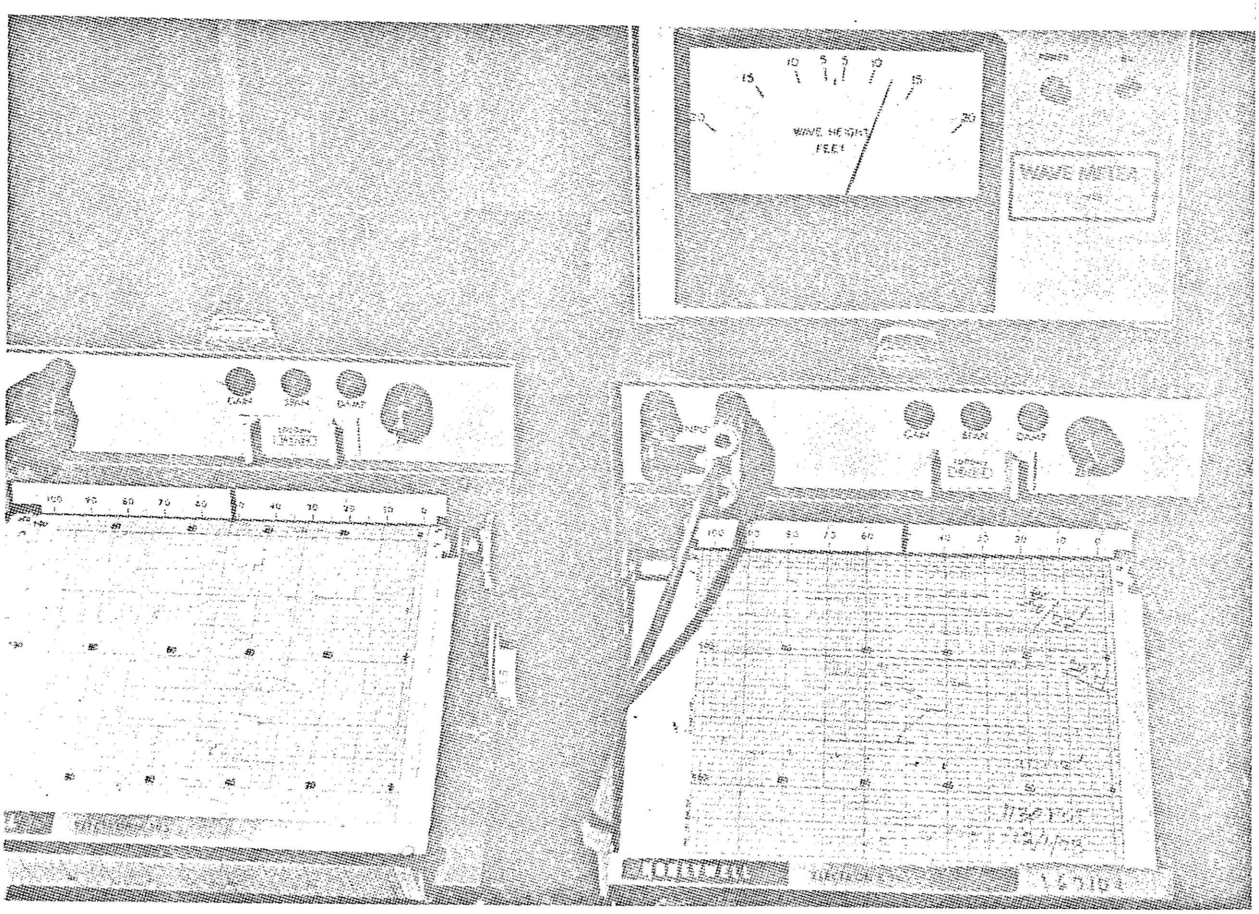

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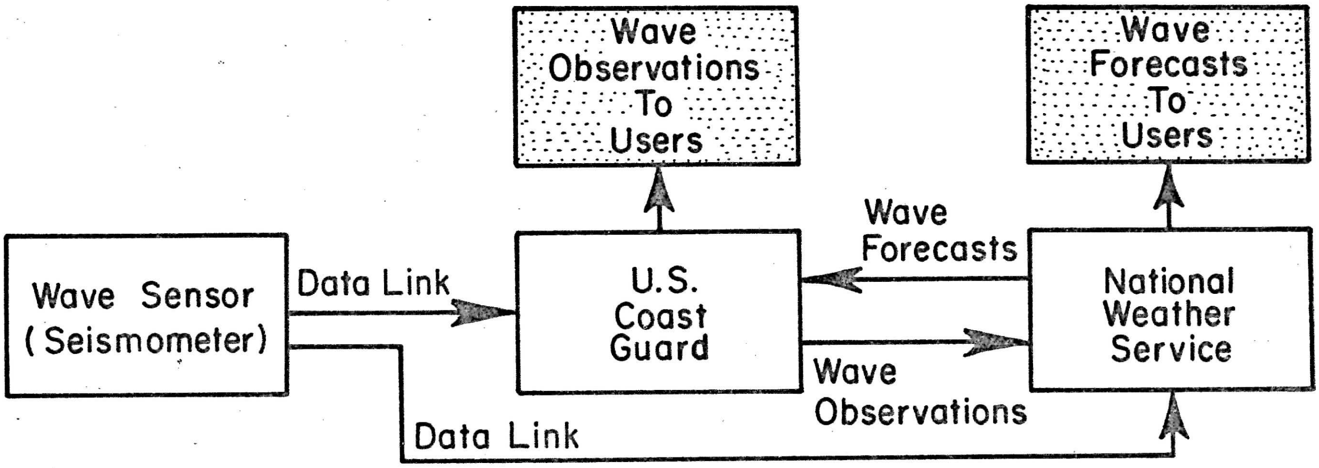

Figure 8.--Chart showing proposed flow of wave information from seismometer sensing sites to users. Data will be transmitted via telephone data links to U.S. Coast Guard and National Weather Service.

4. Equipment is not subject to loss, since it is not exposed to ocean currents, turbulent surf, shifting sands, etc.
5. Initial cost of system procurement and installation is relatively small in comparison to costs for traditional wave sensing systems.
6. Maintenance and servicing costs are small.

Figure 8 shows a currently proposed flow of coastal wave information under Oregon State University's Sea Grant development program. Present plans under the Sea Grant program are:

1. To test this system at additional sites along the coast of the northwestern U.S. (e.g., the Cape Disappointment Coast Guard Station at the Columbia River mouth, the Grays Harbor C.G. Station at Westport, Wash., and the Coos Bay C.G. Station at Charleston, Oreg.).
2. To establish permanent wave sensing sites along those parts of the northwestern U.S. coast which are of most critical interest to mariners.
3. To make wave information readily available on a real-time basis to the U.S. Coast Guard, National Weather Service, ships at sea, and the marine community in general.

ACKNOWLEDGEMENTS

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