A BRIEF REVIEW ON DEVICES FOR WAVE MEASUREMENT AT SEA

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ABSTRACT

This paper presents various types of instruments that are used for measuring ocean waves including various sensor types, principles of operation, salient features and data recording system. Different types of resistance or capacitance wave staffs are used to measure waves at the sea surface when a suitable structure is available to mount them. Surface-following accelerometer-type buoys are conveniently used for measuring surface waves in the open sea. Different types of pressure sensitive gauge systems which measure waves from below the sea surface are also used to measure surface waves. Ocean waves are also being measured from moving platforms (ships, submarines, aircrafts and satellites) with sonic surface viewers, radar infra-red beams, stereo-photography as well as lasers.

INTRODUCTION

Measurements of ocean waves has been a problem that has challenged engineers and oceanographers for many years. Ocean waves are random in nature and are generally considered to be made up of complex superposition of many sinusoidal waves each having its own period, height and direction of propagation. Proper understanding and evaluation of the wave climate at a site is necessary for adequately designing and constructing a coastal or an offshore structure. There are strong economic justifications for collecting long-term wave data. Surveys reported in the literature indicate that the annual cost savings to engineering construction alone from good quality wave information may be US $ 200 to $ 1000 million a year worldwide (National Academy of Sciences, 1982). Besides, the safety of vessels and the integrity of offshore structures can be significantly improved as a result of good wave data.

Many devices varying from the human eye to sophisticated electronic instruments have been used for wave measurement. Sometimes complex measuring devices are not required and the human eye would be sufficient particularly for measuring period and velocity of propagation of ocean swell. In the measurement of complex waves, visual estimates would become inaccurate and unreliable. It becomes necessary to use electronic instruments for measuring such waves. Table I gives some of the important wave measuring devices with their salient features. For convenience, the instruments used for wave measurements can be classified into three categories as follows:

A - Instruments which measure waves at the ocean surface. In shallow water, these instruments may be mounted on fixed supports penetrating the water surface (poles or piles), or on floating support in deeper water (buoys and ships).

B - Instruments which measure waves from below the surface (pressure gauges or inverted ecosounders).

C - Instruments which measure waves from above the ocean surface (radar, stereo photography, laser, micro-wave sensor etc) supported on observation towers, air-crafts or satellites.

WAVE STAFFS

Resistance wire wave gauges

The step resistance wave gauges are generally made of sections of say 1.5 m length to facilitate handling and their mounting on to a fixed structure. Each section of the staff contains electrodes spaced at 6 cm intervals and a bank of relays which sequentially close when water submerges the contact electrodes. The circuit provides a voltage to the recorder which is linearly related to the change in water level due to waves. Wave staffs of resistance type are well-known and fairly dependable instruments if used carefully.

In continuous resistance wire staffs, the staff consists of an insulating cylinder wrapped with spiral or un-insulated resistance wire. The changing resistance with changing water surface due to waves is measured in the form of a voltage signal.

Capacitance wave staff

The capacitance wave staff uses an insulated wire sealed at the lower end and partly immersed in the sea water. The insulator is the dielectric of a variable capacitor with the central conductor and the sea water forming the two conductors. Variations of wave height are sensed as changes in capacitors which can be transformed into a proportional voltage signal (Table I).

Parallel inductive cable staff

Parallel inductive cable staff gauge consists of stainless steel cables mounted parallel to each other at a known distance apart. These cables are excited by a high frequency signal(600 KHz depending upon the model). The excitation voltage level changes as the water level changes. This voltage is detected and produce as a water level proportionately signal with special circuit component matching, parallel inductive gauges can be calibrated to an accuracy of 1% or less.

PRESSURE TRANSDUCER BASED WAVE DEVICES

There are fairly large number of pressure transducers that could be used for wave measurement. They can be bottom-mounted or attached to a structure or suspended from a boat. They are associated with a variety

TABLE I : SALIENT FEATURES OF A FEW IMPORTANT WAVE DEVICES

Sensor type	Principle of operation	Features	Data recording system	Some examples on commercially available systems
1	2	3	4	5
Step resistance	Electrodes spaced at discreate intervals along a staff of insulating material immersed in water, electrical circuit completed by presence of salt water between the submerged electrodes and a ground bar produces resistance as a function of the water level. This resistance is converted to a frequency signal which decreases as the water level rises.	Measurement at the surface, digitised directly, self calibrating, calibrating of system is insensitive to changes in wave staff environment, has to be mounted on to a platform or some structure resolution problem caused by elctrode spacing.	Strip chart recorder and/ or digital magnetic tape. Data transmission via cable or radio telemetry and/ or telephone lines.	1) Interstate Electronics Corporation, USA. Model Rs. 200 Portable Wave Recorder. 2) KYOWA Sttoko K.K.Japan Model RSR Relay type wave height recorder 3) Institute of Applied Physics, Netherlands.
Continuous wire wave gauge	The wave sensor consists of a straight or helix of resistance wire wound over a plastic tube with an insulated return wire connected to the bottom of helix. As the water level changes, there is a corresponding resistance change between the sensor's terminals.	Measurements at the surface, inexpensive, mostly for small wave heights, problems with biological fouling and fouling caused by floatsam and oil. water run-up gives rise to problem in wave height, needs a platform or structure for mounting. Calibration not required.	--- do ---	1) NOVA SCOTIA RESEARCH FOUNDATION (CANADA) 2) OCEAN APPLIED RESEARCH CORP. (USA)-Model UMS-807 3) PLESSEY ENVIRONMENTAL SYSTEMS (USA) Model UMS 9610. 4) HYTECH (USA-)Model 9018
Capacitance	The capacitance probe is immersed in water and is connected to the arm of the bridge supplied with steady input. The varying capacitance is measured as the water level changes.	Measurments at the surface, inexpensive, no calibration required, compensation for water temperature provided, water quality does not affect, simplified handling-needs structures for mounting.	--- do ---	1) NEYRPIC (FRANCE) Model 3313 2) OGAWA SEIKI CO.LTD, JAPAN Model OSK 3350, OSK 3352. 3) COMEX EQUIPMENT (FRANCE)
Pressure	Changes in static pressure at a fixed depth below the water surface are used to predict the concurrent surface wave history by employing theoretical expressions and empirical correction factors to the wave pressure record.	Measure wave pressure from below the surface, inexpensive, dependable conversion of change in pressure to wave height by theoretical expression and empirical correction factors	Self recording strip chart and/or digital magnetic tape or data transmission via cable radio telemetry and/or telephone line.	1) VANESSEN (DELFT) -OSPOS recorder 2) FMW ENTERPRISES (USA) wave height recorder Model 750 A 3) Hydro Products, (USA) -Model WR 421, 521. 4) Interstate Electronic Corporation (USA) Model SDP-101.

CONTD.

1	2	3	4	5
		and so only approximate, high frequency wave information is lost.		5) NBA Controls (England) Model DNW-SM 6) Inter Ocean (USA) 7) SEADATA (USA)
Acoustic	The time taken for an acoustic pulse within a narrow vertical beam to propagate from a bottom mounted unit to the surface and by return is related to the path length, viz. the wave amplitude plus depth. The height of water above the transducer can be accurately found by measuring the time between the transmitted and received sound pulses. The device operates as an inverted echo-sounder.	Measurements from below the surface good for long waves, measurement accuracy affected by changes in water temperature and salinity has to be mounted vertical, measurements affected in waters of suspended sediments and bubbles, reflection and reflection by side rays cause distortion in signals.	Strip chart recorder and digital magnetic tape.	1) EDO WESTERN CORP. (UTAM) 2) CROUZET (FRANCE)
Accelerometer	Follows the sea-surface and vertical acceleration is sensed by accelerometer suspended inside the buoy, water displacement history obtained by double integration of acceleration history through electrical circuitry.	Measurement at the surface, information readily telemetred to recorder on shore or on the platform within a distance of 50 km being a platform buoy, it can be deployed with suitable mooring at any desired water depth.	Strip chart recorder and digital magnetic tape. Data transmission via radio telemetry or satellite.	1) Datawell (Netherlands) 2) Estech Ltd. (Canada) Model-266 3) NBA CONTROLS (England) Model WBU-1
Heave, pitch and roll buoy systems	For measuring the direction, the buoy follows the sea surface movements and measures its pitching slope. The pitch, roll heave and heading of the surface slope are measured. In addition some are equipped with meteorological sensors and some are with attached current meter at the bottom which can measure orbital velocities.	----do---- In addition, some are having data telemetry facilities using ARGOS and METEOSAT satellites systems.	Data directly stored in computer for further interpretation.	1) NEREIDES (France) 2) SUBER (France) 3) BERGEN DATA (NORWAY) 4) ENDECO (USA) 5) IKU (Norway), Seatex (Norway)

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1	2	3	4	5
Micro-wave Remote Sensor	Remote Sensing of the Ocean Surface from Stationary and floating platforms. Microwave remote sensor mounted at 50 to 100m above sea surface measures directional wave and surface current measurements with real time processing and presentation of data.	Directional wave and surface current measurements Real time data processing-Data logging capabilities-Measurements undisturbed by platform structure.	Data stored in Central computer for further analysis. Directional wave information is displayed as six wave height spectra,one for each look direction of the antenna. The surface current is displayed as a vector in a polar diagram.	1) MIROS (Norway)
Stereophotography	Experiments have been carried out by mounting cameras aboard a ship or on land or on a platform or on two aircrafts.	Provide information on spatial variability of waves at a given instant of time.	--	--
Spar buoy	Wave height on cylinder floating vertically (Spar buoy) observed by telescope or photographic techniques.	Motion of spar buoy is not negligible particularly for wave energy content near resonant frequency of buoy, readings approximate,buoy may roll thereby reducing accuracy of measurements.	--	--
Radar techniques	Remote sensing of ocean waves by synthetic aperture radar (SAR) can give gross wave characteristics such as dominant wave length and direction.	Though progress is bein made remote sensing of significant wave height and directional wave spectrum is still not on a firm footing.	SEASAT has ben provided with instrumentation such as Radar Altimeter and synthetic Aperture Radar for measuring wave height and wind speeds including spatial wave information using sea surface imageries.	--

of signal processing and recording techniques. Since ocean waves consist of a number of frequency components, a spectral method would be appropriate to estimate surface significant wave height from random pressure fluctuations. These gauges are operated in shallow depths from 2 - 10 m depending upon the wave period range expected, and the accuracy is improved by applying correction factor for depth attenuation. The main advantages of pressure gauges are that they do not require surface penetrating structure, have a high signal voltage output, do not require frequent maintenance and they can operate in salt and fresh water. The main disadvantages however, are that they require signal correction, have limited frequency response subjected to fouling and are difficult to install in some areas.

ACCELEROMETER TYPE DEVICES

Datawell waverider buoy is the most widely used instrument for measuring surface waves. It consists of a strong spherical buoy of 0.7 m or 0.9 m in diameter designed to float on the sea surface. It is installed at sea using a special mooring arrangement with rubber cord etc.to maintain the free floating characteristics of the buoy at a given station (Fig. 1). The waverider follows the sea surface by rising and falling along with it resulting in vertical acceleration of the buoy. It is this vertical acceleration that is sensed by a stabilized accelerometer which is suspended in a plastic sphere placed inside the buoy. Hence, the water displacement history can be obtained by twice integrating the acceleration history through a suitable electrical circuitry. The waverider is designed to transmit the information it measures to shore station or to offshore station upto a distance of 50 km (for waves upto 10 m height) or a distance of 30 km for waves upto a height of 20 m. The receiving unit records the wave information on a strip chart recorder or a digital magnetic tape recorder. Data acquisition procedure adopted by the National Institute of Oceanography, Goa for the waverider buoys is indicated in Fig. 2.

SHIP-BORNE WAVE RECORDER

Ship-borne wave recorders have been developed to measure wave characteristics from ships. There are two types: one is the widely used Tucker's type which consists of a pressure gauge and accelerometer placed at the ship's bottom, and the other is Mark type which is an ultra sonic wave gauge hanging off the bow of the ship. The Tucker's ship-borne wave recorder consists of two accelerometers, two pressure sensors and a central computer unit where the input of the 4 sensors is converted to a wave signal. Along the bottom of the ship at the port side hull as well as at the starboard side hull each accelerometer has been mounted in combination with a pressure type gauge.

Tucker's type of wave recorder has great advantage over other wave measuring systems for operation on a weather ship or a research ship. The most important feature is that it can be used under all weather conditions. This wave recorder is less accurate especially when measurements of every high and steep waves are to be analysed based on calibrations which are carried out usually under much calmer conditions.

DIRECTIONAL WAVE MEASUREMENTS

Directional characteristics of wind generated waves are important not only for understanding wave generation mechanism but also for solving practical problems associated with wave forecasting/hindcasting, ship's

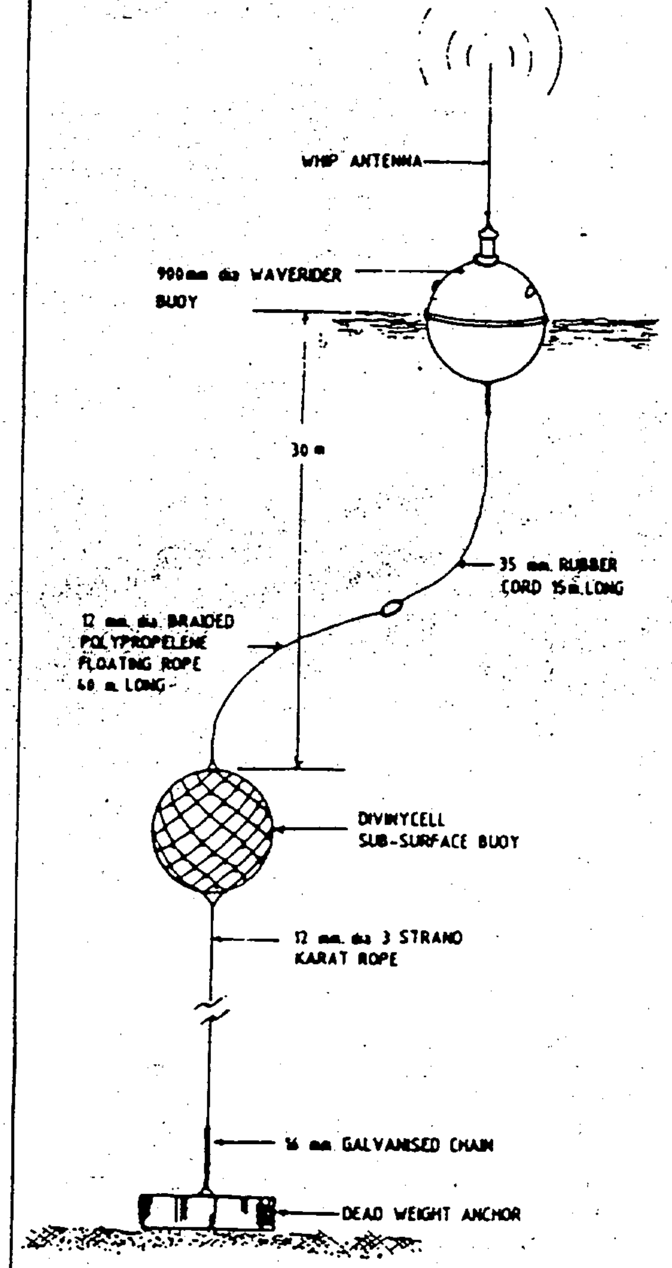

FIG. 1. A TYPICAL WAVERIDER BUOY MOORING IN DEEPER WATER.

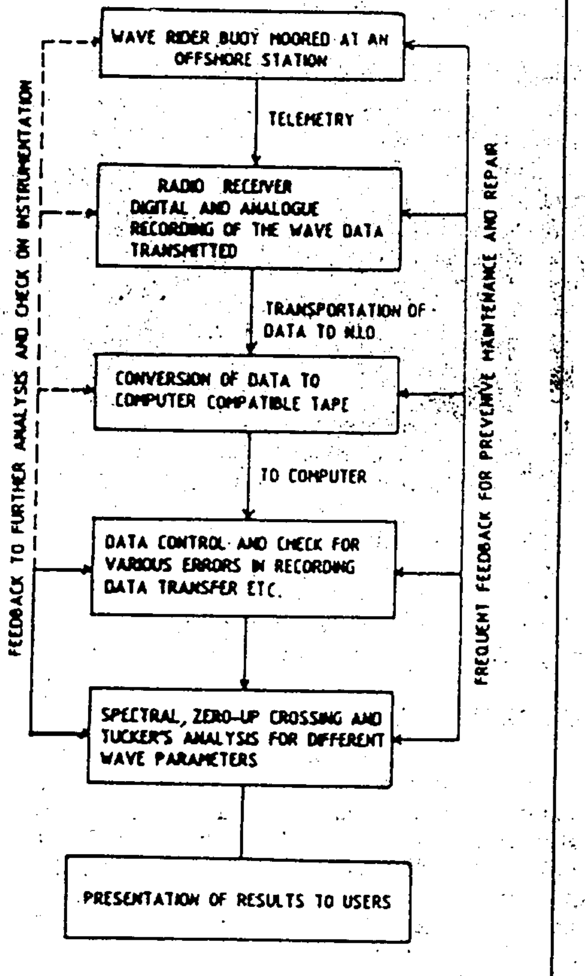

FIG. 2 FLOW CHART INDICATING WAVE DATA ACQUISITION FROM WAVE RIDER BUOY.

response to wave motion and design of coastal and offshore structures. Methods of directional wave measurement can be classified into two main categories: direct measurements of properties within the wave field and the second is, remote sensing through the use of light or radio waves.

Direct measurements:

There are two types of direct measurements. Array type measurements where similar wave characteristics are simultaneously measured by instruments at several points at sea. The instruments are installed in an array which may be one dimensional (linear array) or two dimensional (polygonal array). The second type consists of measurement of several different wave characteristics by means of a special surface following buoy moored at a point.

Array type measurement:

An array of wave measuring instruments separated horizontally in the wave field can yield a spatial distribution of an identical wave parameter. Their inter-relationship can be used to obtain wave directional information. Hasselmann et al. (1973) used a six-gauge line array that consisted of a superposition of two 4-element sub-arrays each having a spacing of D, 4D and 6D. The sub-array for which D = 7 m was tuned for wave length band of 10 m - 150 m and the sub-array for which D = 28 m was tuned for wave length band of 40 m - 600 m. Macovsky and Mechlin (1961) described a possible method of using a line array of inverted echosounders mounted on the deck of a submarine.

Line arrays can be used without ambiguity only when significant wave energy comes from one side of the array. It is sharply tuned only for waves coming generally from direction normal to it. Two-dimensional (polygonal) array is therefore preferred for general use. Munk et al. (1963) used three bottom mounted pressure gauges forming an equilateral triangle with sides of about 300 m for water depth of 100 m. They obtained the direction of long period swell from the data thus collected. Other authors have successfully used two-dimensional arrays in the form of pentagon for computing directional wave spectra.

Buoy type measurements:

Heave, pitch and roll-type of buoys moored at a point to follow the sea surface have been used successfully to measure quantities required for computing directional wave spectra. Some of the examples of such buoys have been given in Table I. Most widely used instrument called WAVEC for wave directional measurement is shown in Fig. 3. Measurement of water surface elevation and two orthogonal components of wave surface slopes have also been used by several authors to compute directional spectra. Instead of surface slopes one can also measure the two components of wave orbital velocities and use them to compute directional spectra. Some authors have used two components of wave force acting on bottom-mounted sphere and the wave surface elevation for computing directional spectra (Grace and Casciano 1969).

Remote sensing:

Remote measurement of waves by instruments mounted above the sea surface have also been used in oceanography. By using stereo photographic techniques and satellite sea surface imageries, directional spectra can be computed. From the stereo pair of overlapping photographs, the

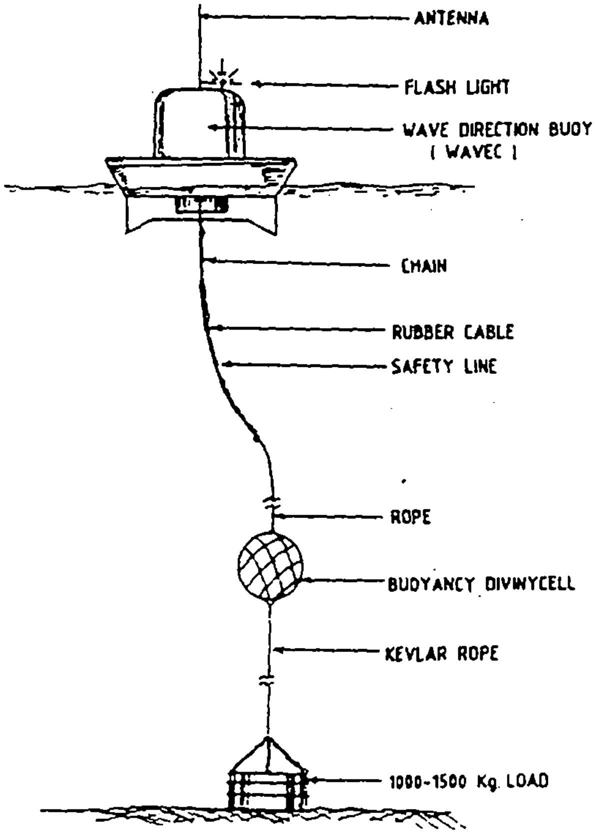

FIG. 3 A TYPICAL MOORING SYSTEM FOR WAVEC BUOY.

directional and energy spectra have been computed based on extensive calculations.

Micro-wave remote sensor (MIROS system) has been designed for remote sensing of the ocean surface from stationary and floating platforms. In this, the sensor head is mounted at about 50-100 m above the mean sea level. The unit comprises of an antenna assembly, a microwave transeiver and a servo platform. During a typical measurement sequence, observations are taken in 6 directions with an angular increment of 30°. The scientific directional wave information is displayed as the wave height spectra, one for each look direction of the antenna. The surface current is displayed as a vector in a polar diagram. The operational data are presented as track histories of the previous 12 hours or as the last value measured.

Remote sensing of ocean waves by synthetic aperture radar located in SEASAT can give gross wave characteristics such as dominant wave length and direction. Laser-based wave instruments have so far been used both from aircraft and fixed platforms mainly on an experimental basis.

CONCLUSIONS

A wide variety of instruments have been used for measuring waves. The Dutch wave rider buoys manufactured by M/s Datawell have been universally accepted for measuring wave height time series because of their ruggedness and reliability. Different types of pressure transducer based wave gauges both self-recording type or remote-recording type are being used particularly for measuring waves in shallow waters. Resistance-type wave gauges are being commonly used in waters where suitable structures are available for mounting them. Taking into consideration the ease of handling and reliability, the WAVEC-heave, pitch and roll-type of buoy manufactured by M/s. Datawell seems to be the best commercially available system for measuring wave directionality at present. With the advances in satellite oceanography and stereo-photographic techniques, remote sensing holds great promist for the future.

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