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WAVES IN THE COSTAL AND OCEANIC REGIONS.

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Abstract

Purpose: The aim of the paper is to assess the waves techniques in the costal and oceanic regions. **Methodology:** One obvious way of measuring waves is to follow the three-dimensional motion of the water particles at the sea surface. This can be done with a buoy that closely follows the motion of these water particles by floating at the surface.

Findings: Ocean waves are generally not observed and modelled in all their detail as they propagate across the ocean, into shelf seas and finally into coastal waters. Such details are generally not required and they are certainly beyond our capacity to observe and compute (except on a very small scale). The alternative is to consider the statistical characteristics of the waves. In advanced techniques of observing and modelling, these statistical characteristics are represented by the wave spectrum, which can be determined either from observations or with computer simulations based on wind, tides and seabed topography.

Key words: *waves techniques, coastal regions, oceanic regions*

INTRODUCTION

Waves at the surface of the ocean are among the most impressive sights that nature can offer, ranging from the chaotic motions in a violent hurricane to the tranquility of a gentle swell on a tropical beach. Everyone will appreciate this poetic aspect but scientists and engineers have an additional, professional interest. The scientist is interested in the dynamics and kinematics of the waves: how they are generated by the wind, why they break and how they interact with currents and the sea bottom. The engineer (variously denoted as ocean engineer, naval architect, civil engineer, hydraulic engineer, etc.) often has to design, operate or manage structures or natural systems in the marine environment such as offshore platforms, ships, dykes, beaches and tidal basins (Holthuijsen, 2010). To a greater or lesser extent, the behaviour of such structures and systems is affected by the waves and some basic knowledge of these waves is therefore required.

If the word ‘waves’ is taken to mean ‘vertical motions of the ocean surface’, then wind-generated gravity waves are only one type amongst a variety that occur in the oceans and along the shores of the world. All these waves can be ordered in terms of their period or wave length. The longest waves are trans-tidal waves, which are generated by low-frequency fluctuations in the Earth’s crust and atmosphere. Tides, which are slightly shorter waves, are generated by the interaction between the oceans on the one hand and the Moon and the Sun on the other. Their periods range from a few hours to somewhat more than a day and their wave lengths accordingly vary between a few hundred and a few thousand kilometers. This is very roughly the scale of ocean basins such as the Pacific Ocean and the Northern Atlantic Ocean and of shelf seas such as the North Sea and the Gulf of Mexico (Grimshaw, et.al, 2004). Although tides may be called waves, they should not be confused with 'tidal waves', which is actually a misnomer for tsunamis.

The wave length and period of storm surges are generally slightly shorter than those of tides. A storm surge is the large-scale elevation of the ocean surface in a severe storm, generated by the (low) atmospheric pressure and the high wind speeds in the storm. The space and time scales of a storm surge are therefore roughly equal to those of the generating storm (typically a few hundred kilometers and one or two days). When a storm surge approaches the coast, the water piles up and may cause severe flooding (e.g., the flooding of New Orleans by hurricane Katrina in August of 2005, or the annual flooding of Bangladesh by cyclones (Holthuijsen, 2010). The next, somewhat smaller scale of waves is that of tsunamis. These are waves that are generated by a submarine 'land' slide or earthquake. They have a bad reputation, since they are difficult to predict and barely noticeable in the open ocean (due to their low amplitude there) but they wreak havoc on unsuspecting coastal regions as they increase their amplitude considerably on approaching the coast (the Christmas tsunami of 2004 in the Indian Ocean being the worst in living memory). The waves at the next scale are even more difficult to predict. These are standing waves, called seiches, with a frequency equal to the resonance frequency of the basin in which they occur (in harbours and bays or even at sea, for instance in the Adriatic Sea).

LITERATURE REVIEW

Observation Techniques

In situ techniques

An in situ instrument may be located at the sea surface (e.g., a floating surface buoy), or below the sea surface (e.g., a pressure transducer mounted on a frame at the sea bottom), or it may be surface-piercing (e.g., a wire mounted on a platform from above the sea surface, extending to some point below the sea surface). Most of these instruments are used to acquire time records of the up-and-down motion of the surface at one (horizontal) location (Apel, 2002). Sometimes a pier, extending from the beach across the surf zone, is used (e.g., the Field Research Facility of the U.S. Army Engineer Research & Development Center in Duck, North Carolina, USA or the Hazaki Oceanographical Research Facility of the Port and Airport Research Institute near Kashima, Japan) or a movable sled pulled along the seabed is used to acquire wave data along a transect or in a small area.

Wave buoys

One obvious way of measuring waves is to follow the three-dimensional motion of the water particles at the sea surface. This can be done with a buoy that closely follows the motion of these water particles by floating at the surface. The most common technique for such a buoy is to measure its vertical acceleration with an onboard accelerometer (supplemented with an artificial horizon to define the vertical). The buoy also moves horizontally, but only over a small distance (roughly equal to the wave height), which is usually ignored. By integrating the vertical acceleration twice, the vertical motion of the buoy and thus of the sea-surface elevation is obtained as a function of time (Grimshaw, et.al, 2007). Owing to the simultaneous horizontal motion of the buoy, the waves in the record tend to look more symmetrical (around the mean sea level) than they actually are. In reality, the crests are slightly sharper than measured and the troughs are slightly flatter. In addition, a buoy has a finite mass and size, causing the buoy generally to underestimate short waves and to resonate at its natural frequency (the Eigen frequency; thus overestimating waves near this frequency). For instance, the diameter of the NDBC buoys in the USA, which usually carry a large array of meteorological sensors, may be as large as 10 m, whereas the diameter of the WAVERIDER buoy (of Datawell, the Netherlands, which is the most commonly used buoy) is less than 1 m. In addition, a spherical buoy tends to avoid the steep parts of waves, circling around the crests of steep waves and thus avoiding maxima in the surface elevation (Grimshaw, et.al, 2004). A buoy with a flat hull (e.g., a disc-shape) may even capsize in a steep wave. Some of these effects are known and can be corrected for in the analysis of the wave records. In spite of these shortcomings, buoys perform well in general.

Wave poles

When an offshore platform is available or purpose-built, a wire can be suspended vertically from that platform from above the water surface to a point somewhere beneath the water surface. The vertical position of the water surface can then be measured as it moves along the wire (the instrument is called a ‘wave pole’ or a ‘wave staff’). An obvious technique is to measure the length of the wire above the surface, e.g., by measuring the electrical resistance of this ‘dry’ part of the wire. In practice two wires or one wire with a string of electrodes is used, which short-circuit at the water surface (Uchiyama, et.al, 2010). Another technique is to measure the electrical capacitance of two parallel electric wires or of a single electric wire within an insulating rubber cord. It is also possible to send a high-frequency electrical signal down the wire, which will reflect at the water surface, again determining the position of the water surface (Holthuijsen, 2010). To illustrate that each in situ technique has its own peculiarities, it may be noted that the water surface, when moving down, tends to leave a thin film of water on the wire with a cusp-like edge between the wire and the sea surface. The dropping sea surface is therefore measured at a somewhat higher level than it would be in the absence of the wire (Grimshaw, et.al, 2007). The error may occasionally be as large as several decimeters in rough seas, but normally the effect is relatively small and it introduces no problems.

Other in situ techniques

The above buoys and poles are the most popular instruments used to observe waves. However, for many reasons (operational, financial etc.) one may want to use other techniques, which are less common but perfectly feasible in their own setting. Some are relatively well known. These are the inverted echo-sounder, the pressure transducer and the current meter (Holthuijsen, 2010). The inverted echo-sounder is an instrument, located at some depth beneath the sea surface, which measures the position of the water surface with a narrow, upward-looking sonic beam. A pressure transducer, located at some depth below the sea surface, can measure wave-induced pressure fluctuations. These fluctuations, combined with the linear wave theory, can be used to estimate wave characteristics. When deployed in a spatial pattern, a set of (at least three) inverted echo-sounders or pressure transducers can provide directional wave information. A current meter, mounted at some depth below the surface, measuring the wave-induced orbital motion, can also be used to estimate wave characteristics (Reguero, et.al, 2019). With this instrument, directional information of the waves can be deduced without additional instrumentation, because the current is measured as a (horizontal) vector, i.e., with direction and magnitude. Sometimes, a combination of instruments is used (e.g., an inverted echo-sounder with an acoustic current meter or a set of inverted echo-sounders radiating at slightly different angles upwards from one under-water support.

Remote-sensing techniques

Instruments that are mounted above the water surface on a fixed or moving platform are called remote-sensing instruments. The platform may be an observation tower at sea, a ship, an airplane or a satellite. Some instruments need not look downwards and these may therefore be located on land. The principle of these remote-sensing techniques is to receive reflections off the sea surface of visible or infra-red light or radar energy. The most important operational difference from in situ techniques is that large areas can be covered (nearly) instantaneously or in a short period of time, particularly if the platform is a satellite (Woodworth, et.al, 2019). However, remote sensing is often experimental and rather more expensive than in situ measurements. Then again, governments and international organizations often subsidize remote sensing and the costs of remote sensing are usually shared with many other users so that remote sensing may still be financially feasible for the individual user.

Imaging techniques

Photography is an obvious technique to observe waves. With stereo-photography it is actually possible to obtain a three-dimensional image of the surface. It is an old and well-established technique for measuring terrestrial topography: a high quality camera looking vertically down from an airplane takes photographs every few seconds of overlapping sections of the terrain below. The differences (parallax) in the overlapping photos can be converted into elevations, thus creating a three dimensional image of the terrain (Murtugudde, et.al, 2000). When this technique is applied to the moving sea surface, one camera is not enough because the surface itself would change between one photo and the next – if these photos were taken in sequence. For applications at sea, therefore, two synchronized cameras are required, usually operated from two airplanes flying in formation.

Conventional ship's radar is normally used to detect hard obstacles around a ship, i.e., obstacles that are potentially dangerous to the ship (marine radar, with its well-known screen, called the Plan Position Indicator or PPI, showing a scanning, map-like image of the surroundings). These radars are therefore always set to show the reflections off such hard surfaces. However, they can also be set to show the reflections off softer surfaces such as a beach or waves (which are normally considered to be 'clutter') (Reguero, et.al, 2019). Such reflection off the waves is mostly due to resonance between the radar waves and features at the water surface (Bragg scatter). Since the radar wave length is usually in the centimeter range, only very short water waves reflect the radar waves (capillary waves, which are generated by wind, current or by breaking waves, but otherwise dominated by surface tension). These very short waves are modulated by longer waves (the waves that engineers are interested in) because, due to the orbital motion of the water particles in the longer waves, they are slightly shorter at the crest than in the troughs of these longer waves (Christensen, et.al, 2018). The radar 'sees' this modulation and it is the modulation pattern that creates the image of the longer waves on the radar screen.

Altimetry

Another technique than photography that uses (visible or infra-red) light is the laser. As a distance meter, or rather, as an altimeter, a downward-looking laser can measure the vertical distance from the instrument to the sea surface rather accurately. It may be mounted on a fixed platform or in an airplane, but not on a satellite where its operation would be hindered too much by the weather. The deployment from an airplane has some special features, because the sea surface is measured along a line (the flight path of the airplane) and the airplane and the surface elevation move during the observation (Melet, et.al, 2020). Another technique by which to operate a laser altimeter from an airplane is to scan the sea surface with a moving laser beam (for instance, reflecting off a rotating mirror), along closely spaced lines at the sea surface, normal to the flight path or in a (forward-moving) circular pattern beneath the airplane. This technique provides a three-dimensional image of the sea surface, practically 'frozen' in time like in a stereo-photo (some distortions occur because the scanner needs time to build up the image and both the sea surface and airplane move in the time during which the scanner builds up the image). This system is called the airborne topographic mapper (ATM) (Illig, et.al, 2018). These altimeter techniques are less cumbersome than stereo-photography but they share many of the operational problems (e.g., they both require a platform above the sea surface, airborne or not, and are weather-dependent).

METHODOLOGY

Wind waves are considered on a short-term and a long-term scale. The short-term characteristics are treated here, under the assumption that the surface elevation is a stationary, Gaussian process. This is usually a reasonable assumption for the duration of a wave record (typically 15–30 min) but sometimes it is also assumed for the duration of a storm (typically 6–12 h), which is almost always an over-simplification. The statistics relate (a) to cumulative effects of the waves, such as the fatigue in structures, and (b) to extreme values of individual waves, such as occur in survival conditions that are used in the design of a structure. For these effects, some of the most relevant quantities are the instantaneous surface elevation, crossings of the surface elevation through certain levels, the crest heights and wave groups (Holthuijsen, 2010). For extreme values, relevant quantities are the largest crest height or wave height within a certain duration (e.g., a storm).

FINDINGS

The first step in describing wind waves is to consider the vertical motion of the sea surface at one horizontal position, for instance along a vertical pole at sea. The ocean waves then manifest themselves as a surface moving up and down in time at that one location. It may sound odd, but it would be entirely legitimate to conclude from such motion, and from such motion alone, that the sea surface is a perfectly smooth, horizontal plane that moves vertically in a rather random manner. This of course is not the case, but we know that only because we have all seen real, three-dimensional, moving ocean waves. Such chaotic motion of ocean waves seems to defy any rational approach. In three dimensions, the situation looks even more problematic. However, a rational approach to describe this apparent chaos is entirely possible.

In a harbour, the amplitude of a seiche may be large enough (1 m is no exception) to flood low-lying areas of the harbour, break anchor lines and otherwise disrupt harbour activities. These waves are usually generated by waves from the open sea, the source of which is not well understood (although some, at least, are generated by storms). Next is the scale of infra-gravity waves. These waves are generated by groups of wind-generated waves, for instance in the surf zone at the beach, where these waves are called surf beat, with periods of typically a few minutes. The period of the next category, wind-generated waves, is shorter than 30 s (Uchiyama, et.al, 2010). When dominated by gravity (periods longer than 1/4 s), they are called surface gravity waves (the subject of this book). While they are being generated by the local wind, they are irregular and short-crested, and called Wind Sea. When they leave the generation area, they take on a regular and long-crested appearance and are called swell (the beautiful swell on a tropical beach is generated in a distant storm) (Christensen, et.al, 2018). Waves with periods shorter than 1/4 s (wave lengths shorter than about 10 cm), are affected by surface tension and are called capillary waves.

CONCLUSION

Ocean waves are generally not observed and modelled in all their detail as they propagate across the ocean, into shelf seas and finally into coastal waters. Such details are generally not required and they are certainly beyond our capacity to observe and compute (except on a very small scale). The alternative is to consider the statistical characteristics of the waves. In advanced techniques of observing and modelling, these statistical characteristics are represented by the wave spectrum, which can be determined either from observations or with computer simulations based on wind, tides and seabed topography.

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