CHAPTER 1

ORIGIN AND GENERATION OF WAVES

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INTRODUCTION

It is no more possible to speak of <u>the</u> origin of ocean waves than it is to speak of <u>the</u> origin of sound waves, or of electromagnetic waves. Different types of waves exist, often simultaneously, and these differ from one another with respect to their origin and generation.

A convenient classification can be made on the basis of wave period, i.e., the time interval between the passage of successive crests at a fixed point. Tentatively we may use the following major divisions (Fig. 1):

Classification	Period
Capillary waves	less than 0.1 sec.
Ultra-gravity waves	from 0.1 sec. to 1 sec.
Ordinary gravity waves	from 1 sec. to 30 sec.
Infra-gravity waves	from 30 sec.to 5 min.
Long-period waves	from 5 min. to 12 hours
Ordinary tides	12 hours to 24 hours
Trans-tidal waves	24 hours and up

These ranges correspond to bands in the spectrum of electromagnetic waves and altogether constitute the <u>spectrum</u> of ocean waves.

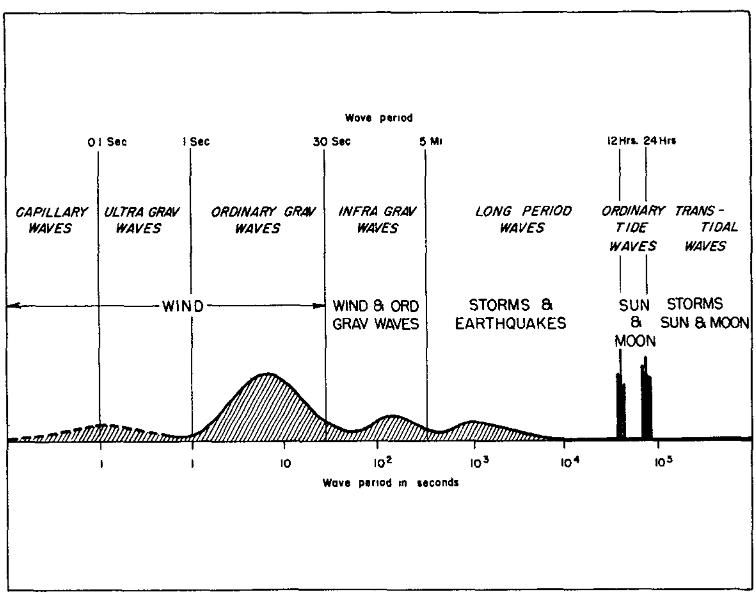

Fig. 1. Tentative classification of ocean waves according to wave period. The forces responsible for various portions of the spectrum are shown. The relative amplitude is indicated by the curve.

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APPLICATION OF SPECTRUM

Virtually all the energy of the spectrum is contained in two of the period ranges: the ordinary gravity waves, and the ordinary tides. These are the ones that can be noticed with the naked eye, the ones that have affected mankind since the dawn of history. In the minds of this group the term "waves" is virtually synonymous with the ordinary gravity waves, and we shall be concerned chiefly with them.

However, it is not just for academic reasons that the entire spectrum is discussed. There are some engineering applications that are definitely concerned with periods other than those of the ordinary gravity waves or the tides. The reason usually has to do with "resonance." For example, an artificial harbor with a natural period of oscillation of 2 min. may develop troublesome 2-min. surges, and these depend largely on infra-gravity waves, even though these waves are only a few inches high and completely obscured by much higher waves of shorter period. A ship with a natural roll of 5-sec. period is greatly affected by waves of about 5-sec. period, but only slightly affected by a 14-sec. swell, even though the swell may be much higher. The effectiveness of RADAR is limited by "sea clutter" due to reflection and scatter from capillary waves, rather than the higher wind waves. There are other examples, and they will be covered in the following chapters.

THE STUDY OF THE WAVE SPECTRUM

The scientific problem is to study the origin of the entire wave spectrum, and, as a final test of such efforts, to predict it. Once the spectrum is known, it is the problem of the engineer to evaluate its effect on engineering structures, harbors, and many other things. There has been considerable success in predicting tides, and for most practical application these predictions are adequate. There has been moderate success in predicting wind waves and swell. This subject is discussed by R. S. Arthur in Chapter 8. Briefly reviewed below is the little that is known regarding the fundamentals of wave generation, starting with the waves of shortest period.

CAPILLARY WAVES

This portion of the spectrum is affected to a larger extent by surface tension than by gravity. Very roughly we may include waves of periods less than 0.1 sec. The appropriate wave lengths are shorter than one inch. The velocity increases with decreasing period and length, but always exceeds 0.75 ft. per sec.

These waves are caused by wind, but we know nothing of their mode of origin. They are greatly affected by surface-active agents, such as oils and detergents. They are rapidly damped by viscous forces, and apparently require winds above 3 ft. per sec. for their generation. These waves determine largely the optical effects of the surface. One convenient way of studying them is to photograph the glitter of the sun on the water surface. These capillary waves are also largely responsible for what might be termed the inherent roughness of the surface. As such they determine the effectiveness with which the wind can grip the water. This in turn enters in the study of currents, the piling up of water by on-shore winds (storm tides), and also in the generation of longer period waves.

ULTRA-GRAVITY AND ORDINARY GRAVITY WAVES

Again we deal with waves which owe their existence to the wind. Two mechanisms by which the wind may cause these waves to grow are, (a) an excess in pressure on the windward side of waves compared to the pressure on the leeward side, (b) tangential drag on the water surface, assuming waves to have a mass transport according to the irrotational theory. These are the two mechanisms which form the basis of the forecasting method described in Chapter 8. They are of about equal magnitude. There are a number of other possible mechanisms for explaining wave growth, and some of these are now being investigated. All these processes already require the existence of a wave, though possibly one of very small height, in order for the wind to transfer energy to it and to make it grow. However, such a distinction between "origin" and "growth" does not appear to be of practical importance. It seems safe to assume that the impulses received by the sea surface as a consequence of the gustiness of the wind assures a steady supply of very low waves of all length.

The outstanding weakness of present theories concerning the generation of waves is that they do not allow for the variability of the ordinary gravity waves. The theories are concerned only with the higher waves present. They say nothing about the character of the waves twice the period of the higher waves, or half their period.

Consider a rather severe storm, capable of raising a sea for which the higher waves are 20 ft. high and have a period of 10 sec. At the same time there will be present longer waves and shorter waves. The longest waves may have periods up to 25 sec. The height of the 20-sec. waves is perhaps only one foot, and to the naked eye these long waves are obscured by the higher waves present. Owing to the fact that in deep water the velocity of the waves is proportional to their period, these long waves will travel ahead of the heavy swell and may reach land several days prior to the arrival of the highest waves. The practical application of these "forerunners" of the swell in providing a warning of higher waves to come (and possibly the storm itself) has been demonstrated in the Atlantic and Pacific.

Measurements of swell, and forerunners of swell, indicate a remarkably slow attenuation of these waves after they have left the storm area. We are recording in California waves from violent storms in all parts of the Pacific to which we are exposed. As a matter of fact, our heavy summer swell has its origin in the roaring forties of the South Pacific Ocean, 5000 miles and 10 days travel time removed from here. Some allowance for a decrease in wave height and a shift towards the longer periods has been made in existing theories. Measurements at Oceanside, California by the Department of Engineering, University of California, Berkeley, indicate that the present estimates of period increase in swell are in error (Wiegel and Kimberley, 1950).

INFRA-GRAVITY WAVES

Instruments especially adapted for the recording of the long waves have revealed the presence of 2-min. waves that are related to the variability in the incoming ordinary gravity waves. A series of high breakers temporarily raises the water level, a series of low breakers permits the level to fall. This oscillation (surf-beat) appears to be propagated seaward from the surf zone. Just outside the surf zone the amplitude of the surf-beat is 10 percent of that of the mean breakers.

These long waves in their travel seaward are greatly affected by the bottom topography over the entire continental shelf. Isaacs, Williams, and Eckart (1951) have shown that they may even be turned around completely and returned to shore. Calculations show that in depths of several hundred feet the orbital velocities near the bottom associated with the surf beat is likely to be larger than the corresponding velocities of the incoming ordinary gravity waves. A pipe line along the bottom at such depths would be affected principally by such long-period waves. Oscillations in bays and harbors (seiches) may be the result of surf beat.

LONG-PERIOD WAVES

Fairly well defined waves of 15- to 20-min. periods have also been recorded at La Jolla and Oceanside, California. The origin of these waves remains obscure, although a correlation with the meteorological situations is strongly indicated. Some of the remarks made in relation to the surf beat apply here also. These waves are small, hardly more than 2 in. in amplitude.

Waves of somewhat the same period, but of much larger height, result from the sudden displacement of the sea bottom during submarine earthquakes. Popularly these are known as "tidal waves," but since they have nothing to do with the tides, we prefer to use the Japanese word "tsunamis." In Hilo, Hawaii, a tsunami of destructive intensity seems to come about once every 20 years. Protection against such tsunamis is certainly the No. 1 problem of coastal engineering in the Hawaiian area. The construction of a 15 ft. sea wall along the waterfront in Hilo is now being seriously considered. Fortunately the coast of Southern California does not seem to be subject to destructive tsunamis. The largest tsunami waves here that have come to my attention were recorded in the Mission records of San Diego: 2.5 ft.

ORDINARY TIDES

These are caused by the sun and moon. As a whole, the two contribute about equally, since the very much larger mass of the sun is just about compensated for by its larger distance. Most of the energy goes into the semi-diurnal and diurnal periods (the "ordinary" tides), and these are of the same order of magnitude along our coast as the ordinary gravity waves. In most instances, but not always, the effect of the wind on waves of ordinary tide period is <u>relatively</u> small, and the forecast based only on the astronomic factors is satisfactory. It should be added that the forecasts are largely empirical: only the periods of the components are computed from astronomical considerations, whereas the amplitude and phase of each component is determined from tide records at or near the locality for which the forecast is made.

TRANS-TIDAL WAVES

There are various components of solar and lunar tides in this range of periods, but these tend to be outweighed by the meteorologic factors. The situation is therefore reversed from what is found in the ordinary tide range.

In the river Thames non-tidal variations in water level of several days duration have been observed. There seems to be a correlation between such variations and the passage of storms over the Wyville Thompson ridge in the North Atlantic.

There are also seasonal variations in water level related to the variations in ocean current, and hence indirectly to the prevailing winds. It is not generally known that along the coast of Southern California the mean sea level in the summer is 2/3 of a foot above that in the winter.

We could go on, and consider variations in sea level that have taken place in climatic cycles. For example, the oceans are believed to be rising 1/2 foot per century.

CONCLUSIONS

Any shore installation is, therefore, under the influence of waves ranging in periods from milliseconds to years. The underlying causes of these waves are the winds, directly or indirectly; the sun and moon, and submarine earthquakes. By far the largest part of the spectrum reflects the action of the wind. The wind is most effective in raising waves whose periods lie between 5 sec. and 15 sec. These can be predicted, in a manner. The fact that shorter and longer waves are of smaller height does not mean that they are of no practical consequence. In 10 to 20 years we may be able to predict the entire spectrum of wind generated waves.

REFERENCES

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