be especially given to the accuracy with which the position of the sounding has been determined. It should be borne in mind that a sounding is three-dimensional; in other words, it is of actual value as a vertical measurement with respect to the ocean bed only if the accurate geographical position of such sounding can reasonably be relied upon. Modern science presents great resources and numerous methods to help the hydrographer in the art of drawing up surveys. The geologist, on the other hand, should accept for his physiographic studies only data obtained by applying modern methods and scientific technique. Modern hydrographic surveys present a fairly high scientific aspect, and the geologist should accept with the greatest circumspection those data which are not based on these modern principles and which do not answer necessities corresponding to the possibilities offered by science.

DEEP SEA DIVES WITH THE BATHYSPHERE.

(Extract from the *Bulletin of the New York Zoological Society,* Nov.-Dec. 1934, and *The National Geographic Magazine,* Washington, Dec. 1934).

Dr. William BEEBE's deep sea dives with the Bathysphere have already been mentioned in *The Hydrographic Review,* Vol. VIII, No. 1, May 1931, page 245.

During 1934, the oceanographic work undertaken by the New York Zoological Society was resumed at Nonsuch, Bermuda, and the opportunity occurred to perform a series of dives down to 3028 feet with the Bathysphere, which has been much improved within the last few years. During a noteworthy dive, which lasted three hours, the occupants were able to note some extremely interesting data concerning fish in the very heart of their element. A report on the various dives effected and the results obtained has been published by the New York Zoological Society in its November-December 1934 Bulletin, as also in an article by Dr. William BEEBE in the December 1934 issue of *The National Geographic Magazine,* which includes a particularly striking series of coloured photographs relative to the dives.

GREAT SEA WAVES.

by

LIEUTENANT-COMMANDER R. P. WHITEMARSH, U. S. NAVY.

(Extract from the *United States Naval Institute Proceedings,* Menasha, Wisconsin, August 1934. p. 1097).

The fascinating study of sea conditions, in great vogue over fifty years ago, has, with the advent of steam and its detracting activities, come into a measure of neglect. It is significant that authorities of to-day in their treatment of the sea find it necessary to refer to theories developed in 1888, 1890, 1900, and 1904 for their latest data. Some of the best work was accomplished by the German scientists von HELMHOLTZ, BORGEN, and ZIMMERMANN many years ago in studies of the North Sea.

The extreme height of storm waves is one phase of the subject on which there is no evident agreement. Waves of seismical origin are not considered in this discussion, except that one may serve as an example of a wave of extreme height. In August, 1883, there was an earthquake central near the Island of Krakatoa, Sunda Strait. One of the resulting seismical waves measured 135 feet (41.1 m.) in height, which figure is generally accepted because of the thorough investigation which followed.

It is a problem to know what to believe when the height of storm waves is under discussion. Starting modestly we learn that waves of 90 metres (295 ft.) length and 3 metres (10 ft.) height are not uncommon with strong winds in the open sea. One source of information states that 50 feet (15.2 m.) may be taken as the highest waves found in the open sea. This authority goes on to explain that a hurricane with an 80-knot wind would seem to produce a 40-foot (12.2 m.) wave, so that the greatest height of waves as found in the open sea and verified by observations is approximately 40 feet.

REISENBERG gives the observed height of seas as approximately 40 feet (12.2 m.) where there is plenty of "fetch" for the seas to make up in, but concedes that waves of from 50 to 60 feet (15.2 to 18.3 m.) in height are possible but rare. In a table of about 100 observations, seas 46 feet (14.0 m.) in height have been noted and in one case there was a height of sea in excess of 50 feet.

The more the experience with the sea, the greater the acceptable height becomes. The greatest waves, according to a noted British authority, are believed to occur in the North Atlantic Ocean and in the great Southern Ocean, where waves 560 feet (170 m.) in length and 50 to 60 feet (15.2 to 18.3 m.) in height have been experienced. In February, 1841, French marine officers acting under instructions of ARAGO, observed sea waves of from 42 to 50 feet (12.8 to 15.2 m.) in height in the vicinity of the Azores. The *National Encyclopedia* shows that during very severe and lasting storms, heights of as much as 75 feet (22.9 m.) have been observed.

Having established a presumption against waves of extraordinary height, we make bold to announce the observation of a great sea wave. On February 7, 1933, a great sea wave of 112 feet (34.1 m.) high was observed by personnel of the U. S. S. *Ramapo*. This observation was made without prior knowledge of the theory of wave development or other studies of the sea. However, this is one of the largest sea waves found in an aggregate of over 1,021 man-years of seagoing experience.

The length of sea waves is of interest inasmuch as this affords one means of checking the height graphically and by formula.

It is natural that the greatest waves should be observed in the larger oceans where there are no land obstructions for thousands of miles. Many of the longest waves have been found in the South Pacific Ocean where lengths of from 500 to 1,000 feet (152 to 305 m.) and periods of from 11 to 14 seconds have been observed.

The longest wave observed was one 2,600 feet (792 m.) long which had a period of 23 seconds. It was measured by the French Admiral MOTTEZ in the Atlantic Ocean near the Equator in Longitude 28° W. This wave was travelling at a speed of 77 miles per hour. Waves varying from 500 to 600 feet (152 to 183 m.) in length are sometimes encountered in the Atlantic Ocean, but the usual length of waves is from 160 to 320 feet (49 to 98 m.) with periods of from 6 to 8 seconds.

Another observation of value in determining the characteristics of waves is the speed at which waves travel. There is as wide a divergence in opinion regarding the speed of translation of waves as there is on the subject of wave heights. There is a definite relation between the period of waves, their length, their height, and force of wind, which authorities have attempted to express in precise formulas. However, all seas in the same storm will differ with each other while each wave is being constantly increased or decreased in size.

As a matter of fact, observations have shown that sea waves tend to travel at approximately the same speed as the winds which cause them. For example, from March 19, 1933 to April 3, 1933, the *Ramapo* accompanied a constant trade wind of 14 knots on a great circle course for 3,600 miles. It was observed that the following seas travelled at a speed remarkably close to that of the trade wind, since they slowly overtook the ship travelling at 10 knots' speed.

KRÜMMEL states that while wind velocity is increasing, the wave velocity is less than that of the wind, but that as soon as the wave has reached its maximum height, further wind force is expended in increasing its length, and therefore its speed, until eventually the wave travels faster than the wind.

This information substantiates, or is substantiated by, observations of 55-knot wave velocity during a wind velocity of 60 knots, and applying to the particular sea wave under discussion.

The weather condition in the mid-Pacific in February was unique in that it contained every element favorable to the development of extraordinarily high waves. The *Ramapo* was proceeding from Manila to San Diego in Latitude 34°30' N. On February 3 the barometer, which had stood at 30.20 ins., began to fall. During the 7-day period of stormy weather which followed, the ship travelled from Longitude 169° E. to Longitude 155° W. on an easterly course.

From the meteorological plotting chart prepared in the *Ramapo's* aerological office, it was noted that a well-defined low (29.00 ins.), central near Dutch Harbour, Alaska, extended from the Arctic Circle to a secondary low immediately to the northward of the Hawaiian Islands. On February 4 this secondary low developed and deepened to a minimum pressure below 29.10 ins., and apparently drew much of its strength from the northern low whose minimum pressure rose to 29.60 ins.

This system of lows displaced the normal high-pressure area to the eastward of the Hawaiian Islands, whose centre usually shows a pressure of 30.20 ins. This resulted in a striking system of high pressure areas extending along the entire coast of North America from the Arctic Ocean to the tip of Lower California.

Incidentally, such a development is characteristic of winter cold snaps in the West and Middle West, since its normal clockwise air circulation draws down the polar air mass from the arctic regions. In this case, extreme low temperatures (— 40°) were registered in the Middle West with blizzards and snow as far east as New York. These facts are mentioned to indicate the far-reaching influence of an extreme weather condition. The disturbance was not localized as is the case with a typhoon, but reached all the way from Kamchatka on the Asiatic continent to New York. This permitted an unobstructed "fetch" of thousands of miles, with winds from a constant direction, all contributing to extremely high seas.

On Sunday, February 5, we crossed the 180th meridian practically in the middle of the vast Pacific Ocean. Sunday was repeated. The third low whose presence we suspected immediately to the westward became a reality.

The barometer dropped to 29.58 ins. to the accompaniment of winds from astern force 8 and 9. These winds lasted for four hours and resulted in a rather rough sea. This short blow is considered our entry into the real low-pressure area with which we travelled for the next four days.

By the end of the second Sunday, February 5, the barometer had slowly settled to 29.51 ins. and winds of force 3, 4, and 5 were experienced. The wind held to the west. The system of three lows showed marked intensity with minimum pressures below 29.00, 29.30, and 29.20 ins., and occupied much of the North Pacific Ocean.

On February 6, the barometer dropped from 29.51 to 29.24 ins. without any material difference in wind or sea. The wind was a strong breeze of 30 knots' velocity and caused a moderate sea.

The barometer remained at 29.24 ins. for five hours, during which time the elements began to give evidence that something out of the ordinary was about to happen. After two hours the wind became a moderate gale, force 7 or 35 knots, and the sea at once increased to a heavy swell. These conditions were maintained for three hours without change when, for the first time, the barometer rose one hundredth to 29.25 ins.

The result was immediately apparent. At this time the wind increased to a fresh gale of 42 knots while the sea effect was slightly increased. The following hour disclosed a whole gale of 58 knots' force and mountainous seas. This occurred at 2200 on February 6, as we began to leave the vicinity of the low centre near which we had been cruising for over two days. We maintained our easterly course with the wind almost directly astern. It would have been disastrous to have steamed on any other course.

Although the ship's draft aft was 21 feet 10 inches (6.65 m.), the propeller raced to such an extent upon the passing of the crest of a wave that it became necessary to reduce speed at 2300. The storm reached its height between 0300 and 0900 when winds up to 68 knots in velocity were clocked with the anemometer. We occupied the bridge from 0400 to 0800 and personally verified all data. The winds came in gusts and squalls during which the greatest velocities were obtained and the highest seas were observed. This fact gives additional evidence that sea waves travel at approximately the same speed as the wind which accompanies them. It is significant that when, at 1000 on February 7, the wind dropped to force 8, the seas were simultaneously reduced from "mountainous" to "very rough".

The great system of three low centres was consolidated during the height of the storm experienced by the *Ramapo* with extreme activity as the result. An extraordinary depth of 28.40 inches of barometric pressure was noted on February 8, 1933. The ship emerged from the low pressure area on February 9, just one week after entering it.

The weather condition may be briefly summarized. February is notoriously the most stormy month in the North Pacific Ocean. And from all reports this was the most extensive and severe storm of the year. The *Ramapo* was in a position to experience the full force of the storm. The height of waves was materially greater than that noted when the vessel was forced to take reduced speed for three days in a typhoon near the Mariana Islands in October, 1929.

The conditions for observing the seas from the ship were ideal. We were running directly down wind and with the sea. There were no cross seas and therefore no peaks along wave crests. There was practically no rolling, and the pitching motion was easy because of the fact that the sides of the waves were materially longer than the ship. The moon was out astern and facilitated observations during the night. The sky was partly cloudy.

Probably no two seas were identical in length and height. They varied from 500 to 750 feet (152 to 229 m.) in length of sides, or total wave-length of 1,000 to 1,500 feet (305 to 457 m.), as measured by the ship itself and the seaman's eye. This is verified by motion picture film taken during the morning watch. The *Ramapo* is 477 feet 10 inches (145.6 m.) in length. For purposes of illustration, a conservative wave length of 1,180 feet (360 m.) is assumed. It was noted that the ship's entire length glided down the lee slope of waves an appreciable time before the crest overtook the stern. The vessel was dwarfed in comparison with the seas.

The period of the largest sea wave was 14.8 seconds as determined by stop watch. Similarly a wind velocity of 66 knots was taken and verified, although the average velocity for several hours was 60 knots.

Due to the extreme simplicity of the determination of the height of sea waves in this particular case, none of the factors, including wave length, period, and wind velocity is required in the solution. These factors are of interest in checking observations and proving formulas. The height determination is by construction wherein the ship itself measured the seas.

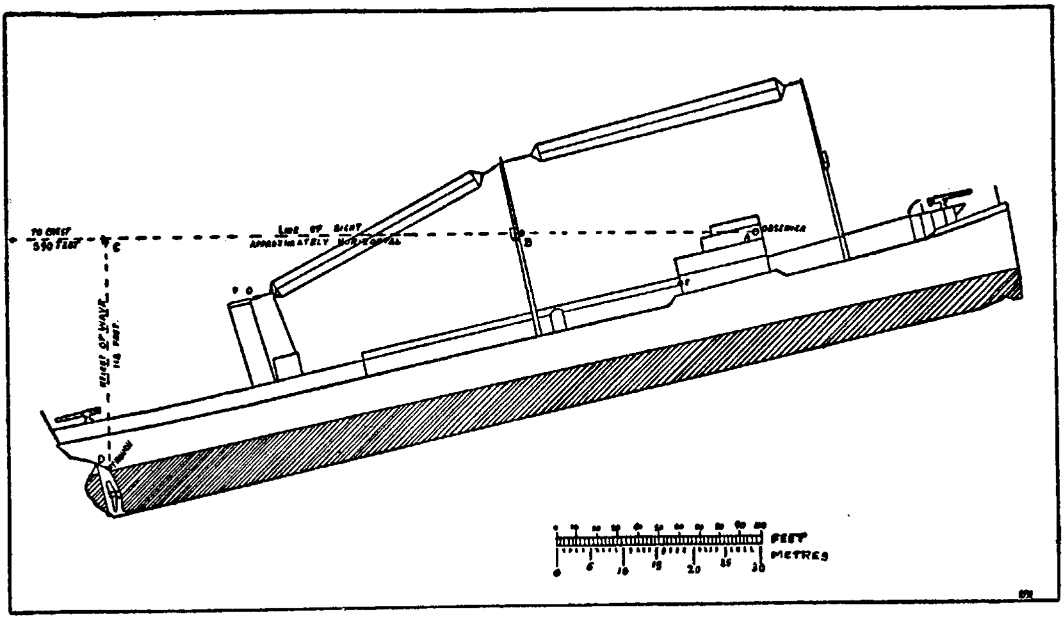
Among a number of separately determined observations, that of Lieutenant (J. G.) Frederick C. MARGGRAFF, U. S. Navy, is employed, although one other observation similarly taken by another observer gave greater heights of sea waves. The selected observation gives a height of wave of 112 feet (34.1 m.) compared with other observation of 82, 86, 107, and 119 feet (25, 26.2, 32.6 and 36.3 m.), all covered by construction based on sworn affidavits of different observers.

Mr. MARGGRAFF declares that while standing watch on the bridge between the hours of 0000 and 0400 on Tuesday, February 7, 1933, he saw seas astern at a level above the iron strap on the boom located against the mainmast crow's nest, and that at the moment of observation the horizon was hidden from view by the waves approaching from astern. Mr. MARGGRAFF is 5 feet 11 3/4 inches (1.81 m.) tall. The ship was not listed and the stern was in the trough of the sea.

This gives an exact line of sight from the bridge to the crest of the wave. This also determines the altitude of the ship with the angle of pitch. While the observer was obviously below the line of crests, the amount is indeterminate. It would reduce the height of the observed wave astern if this line were considered truly horizontal. Such an assumption is made in arriving at a height of 112 feet (34.1 m.).

The stern of the ship had been sinking into the trough of the oncoming sea, up to the instant of observation, due in part to lack of water support aft. Water rolled aboard aft when the stern was near the crest. Nearly normal conditions of draft obtained when the stern was almost at the trough. For all practical purposes, the trough was at the water line at the stern, 21 feet 10 inches (6.65 m.) above the keel.

The accompanying figure illustrates the attitude of the ship at the instant the heigth was determined. Considering the line of sight in the plane of the horizon, we measure vertically downward to the trough to obtain the wave height. The construction was from ship's plans. The height is shown to be 112 feet (34.1 m.) from this construction. The height determination depends solely upon the observed line of sight and the accuracy of these plans.



The form which a sea wave tends to take is best represented by the swell, but is correct with some modifications for the storm waves. This form is a trochoid curve or prolate cycloid. It may be graphically represented by tracing a point on the plane of a circle as it rolls along a straight line. It may vary from a straight line to the limiting form of the trochoid, depending upon the strength of the elements causing wave formation. A modified trochoid curve was used to verify the wave measurement and gave an angle of pitch for the ship similar to the observed angle.

From the motion pictures taken during the storm, it is known that the ship's stern was inclined downward at an angle of 5 degrees when the horizon astern disappeared from view in one case. Further descent of the ship into the trough may be termed a descent below the plane of the horizon. The ship was inclined downward at an angle of 11°50' at the instant the observation of the great wave was made. Angles were measured using the ship's normal water line according to draft. Also, the ship pitched through an angle of 24°12' according to sextant and other lines of sight to the horizon.

Motion pictures also indicate the extremely small degree of rolling during the storm.

These data make available an approximate check of the wave height. At the instant of observation, the vessel was lying up the inward slope of the wave. Whatever distortion of the trochoid wave form occurs in a storm tends to increase the angle of slope of the lee side above that of the windward side, since the crests break forward in whitecaps. By construction we note, as previously stated, that the ship's water line intersects the line of sight at an angle of 11°50'. Taking this angle as the average slope of the lee side of the wave, and the distance 600 feet (183 m.) up the slope of a wave 1,180 feet (360 m.) long, a right triangle is available with an hypotenuse of 600 feet. The calculated height of the wave becomes 600 sin 11°50', or 123 feet (37.49 m.).

This compares with the reported height of 112 feet (34.1 m.). An error is introduced in considering that the slope is a straight line, but a moment's reflection will show that this is on the side of conservatism. The steepest slope of the wave curve occurs at or near the crest.

This check is in turn subject to verification by various accepted formulas which apply to wave lengths. Quantities used in these formulas included gravity as 32.17 feet per second, one metre as 39.37 inches, period of the wave as 14.8 seconds, wave velocity observed at 55 knots, height of sea as 112 feet, and wind velocity as 60 knots. The length of this wave, according to formula, is as follows :

Length.		By Formula.	Based upon.
feet.	metres.		
1180.0	359.7	Observed.	Ship length.
1121.5	341.8	A	Period.
1685.0	513.6	B	Wave velocity.
1819.0	554.4	C	Wave velocity.
3859.0	1176.2	D	Height.
1128.0	343.8	E	Wind velocity.
1798.7	548.2	None.	Average.

Although in some cases the calculations agree very closely with observations, certain results are irreconcilable. If a greater length of wave than that selected were taken, it would only operate to increase the height of the wave, the angle of slope remaining as observed.

It is principally because the two observations of heights of 82 and 86 feet (25 and 26.2 m.) were taken from positions two decks below the bridge deck, and therefore deeper in the trough, that they vary to such an extent from the greater values of 107, 112, and 119 feet (32.6, 34.1 and 36.3 m.) determined from the bridge. Observations from the flying bridge deck or the foremast crow's nest would possibly have determined even more accurate measurements and therefore greater heights of waves.

A further check is available to any individual who may desire to make the test. Comprehension of the significance of 100 feet (30.5 m.) height, for instance, may vary with the individual, but in reality, this is a rather short distance. The individual may test his theory of wave height on the illustrative diagram, by measuring vertically downward towards the trough from point *C* on the line of sight to the crest, a distance which he considers a maximum wave height. A scale is provided for this purpose. The wave form should then be sketched in through this point as the trough. It should be of considerable interest to note what has happened to the ship.

Since time immemorial, seafaring men have been telling the world in their inarticulate way that storm waves attain heights which seem incredible to the rest of mankind. In the absence of satisfactory proof in specific cases, it has been easy to doubt the accuracy of the observations.

Possibly the controversy began in 1837 when Dumont D'URVILLE estimated and reported a wave 100 feet (30.5 m.) high off the Cape of Good Hope. It is significant that an authority of to-day should consider this statement of such a dubious character that probably only seafarers would agree with it.

The privilege of viewing great storm waves of extreme height is a rare one indeed. Furthermore, we have no assurance that the highest waves of the ocean have been observed or measured. If such a wave should ever be encountered, it is probable that all hands would be chiefy concerned with the safety of the ship to the exclusion of any scientific measurement of the phenomenon.

To-day the apologetic method of mariners in reporting seas in violation of the 60-foot (18.3 m.) law of science is as quoted from a *Hydrographic Bulletin* : "A measurement of one sea showed an apparent height of about 70 feet." (21.3 m.).

This particular observation was made in the North Pacific Ocean on December 31, 1932, during a typhoon in which winds of force 12, hail squalls , and a tremendous sea were experienced.

In view of the undisputable experience at lighthouses throughout the world, it is difficult to understand the apparent low limit placed by science on the maximum height of great sea waves. Lighthouse observations support the conclusion that waves reach heights in excess of 100 feet (30.5 m.).

In the winter of 1861, a fog bell 100 feet high on the Bishop Lighthouse, Isles of Scilly, was struck by a sea wave. The breaking crest was formed well above this height and the wave struck with such force that the metal bracket 4 inches (10.2 cm.) thick by which it was supported was broken. The bell crashed to pieces on the rocks below. The sea left sand heavily deposited on the lighthouse gallery.

Occasionally, waves go over the top of the tower of the lighthouse on Minots Ledge, Massachusetts, 75 feet (22.9 m.) above the water.

In severe storms, rocks have been thrown through the lantern glass of Tillamook Rock Lighthouse, 133 feet (40.5 m.) above the ocean. This lighthouse is situated on a rock one mile from the Oregon coast between the 10- and 21-fathom lines and 30 miles from the 100-fathom line. This topographical condition serves to modify the extreme height of seas before they reach Tillamook. The height of 133 feet does not, therefore, represent the maximum height of offshore sea waves.

For instance, in certain localities, such as off the Malabar coast, the seas are entirely ironed out by shoal water prior to reaching land and safe anchorage is provided along an otherwise unprotected coast.

The intriguing subject of sea wave study is in the process of development and enjoys no great solidarity of opinion. It is necessary that the scientists receive the co-operation and aid of men who go to sea in ships if improvement is to continue. Perhaps authorities in the past have been radically conservative in the treatment of sea waves. A 60-foot (18.3 m.) wave as the highest of all time lacks conviction.

There should be no intimation that the modern sea wave exceeds that of the past in size. The theory and law of waves are excellent guides, but, in accordance with the present custom, if the laws cannot be enforced, they should be repealed.