EXPERIENCE WITH RECORDING OF STORM WAVES, SWELL AND TIDE USING AN INVERTED ECHO-SOUNDER OFF DURBAN (South Africa)

by Jan M. JORDAAN Jr. (*)
B. Sc. (Eng.), Sc. D.

Note on Author. — Jan M. Jordaan, Jr. was born in Cape Town, South Africa on 12 February 1932. After graduation with a B. Sc. degree Engineering from Witwatersrand University (Johannesburg) in 1951, he obtained the M.S. degree at Wisconsin University in 1952 and the Sc. D. in Civil Engineering at Massachusetts Institute of Technology in 1958. He is presently engaged on coastal engineering research at Durban with the South African Council for Scientific and Industrial Research.

ABSTRACT

The paper describes the principle of continuous echo-sounding and recording of the undulating sea surface from a fixed point, by means of an acoustical pulse-transmitter-and-receiver situated on the sea floor on the continental shelf. The sounder is connected by submarine cable to the shore-based receiver.

The procedure followed in installing and adjusting such an inverted echo-sounder off Durban and laying the cable to shore is briefly described. Features of the records obtained for a six month period, such as definition, accuracy, peakedness and multiple traces are discussed, and a summary of the results obtained for the recorded wave characteristics for Durban are given.

INTRODUCTION

Durban is one of the Republic of South Africa's most important port cities and is situated on the South-East coast of Africa (Fig. 1). In order to plan future harbour and beach developments, a comprehensive study of

(*) Head of Hydraulics Division, National Mechanical Engineering Research Institute of the South African Council for Scientific and Industrial Research.

sand travel along the coast was undertaken and, as a part of this study, the necessity of recording the representative wave conditions for this area arose.

Up to that time (1961) no actual wave measurements of importance had been made in this area. Consideration of available wave recording methods led to the choice of an inverted echo-sounder wave-recorder that had been recently developed by the firm Kelvin and Hughes Ltd. At the time of its choice no guarantee could be given that the recorder would be capable of recording the waves of expected heights in the vicinity of twenty feet, especially not for aerated water conditions. Estimates by local persons of the maximum wave heights likely to occur here varied widely, and it was decided to accept the risk and try the inverted echo-sounder. The main advantage of a direct wave height recording (as against the attenuated wave-heights obtained by pressure-sensitive recorders) [2] was decisive in its favour against the odds of its yet unproven performance.

PRINCIPLE OF INVERTED ECHO-SOUNDER WAVE-RECORDING

The instrument used was a K-H Mark 26 A/F M/c. 23 Wave and Tide Recorder and, as said, was bought without guarantee as to its performance as storm-wave recorder. It resembles in all respects, except the special transducers, minor components and the submarine cable, the standard echo-sounding equipment of the same make.

The transducers, in the case of the installation at Durban, were mounted on a base or platform 6 feet above the sea floor in 76 feet water depth at a point about 5000 ft offshore (Fig. 2). The acoustic pulses of 30 Kc carrier frequency are sent at a frequency of 533 per minute to the transmitting transducer via a five-core shielded submarine cable, 6000 ft in length. The audible pulses or "clicks" are propagated from the transmitter upwards through the surrounding water mass and are reflected by the free-water surface, which is varying in height due to the waves (and tides). The reflected pulses are detected by the receiving transducer below, mounted adjacent to the transmitter, and are conducted via submarine cable back to the amplifier and rotating-arm recorder on the shore end.

As in the case of normal echo-sounding, the point of reflection off the water surface is that of shortest separation from the transducers [1] and, therefore, due to the wave slope, generally non-vertical by a few degrees (Fig. 7). However, at the instant that either the wave crest or wave trough passes vertically over the transducers' position, the shortest echo sounding path is always vertical; hence the difference of the soundings taken at the crests and at the troughs give the true heights of the waves. As this measurement derives entirely from the velocity of sound in the water, no discrepancy, attenuation factor, or calibration fall-off can enter, and the measurement is therefore reliable as long as a signal is recorded. The velocity of sound varies by a few per cent due to temperature and salinity fluctuations, but for Durban these conditions are near-constant, and for wave recording, in general, can be considered constant. Fig. 7 shows how the successive soundings represent the passing wave-train. The effect of slightly " pinching " the recorded wave-crests to a somewhat sharper curvature is seen, as well as the creation of multiple or overlapping traces when certain geometrical relationships during very short, high waves (e.g. storm waves) are satisfied. Where such multiple reflection occurs it is in some cases possible by simple geometry (Fig. 11) to obtain values of wave length directly. (See Appendix).

The transducers have a conical field of maximum sensitivity which is stated to be 5.1/2° by 17°. It is stated that, for maximum sensitivity, it is necessary to line the transducers up in a horizontal plane with their longest dimensions parallel of the predominant wave approach direction [3].

GENERAL PLANNING OF THE INSTALLATION

The site chosen for the wave-recorder to be placed was one where the maximum depth of water as well as the most uniform underwater topography slope could be obtained with an economical length (6 000 ft) of cable. The general shape of the continental shelf and the underwater topography is shown in Figs. 1 and 2 on which the chosen site is also marked. This is at a depth of about 80 ft and one mile from the shore.

Various considerations led to the adoption of this particular location. To the North thereof is the harbour entrance and a change to a much

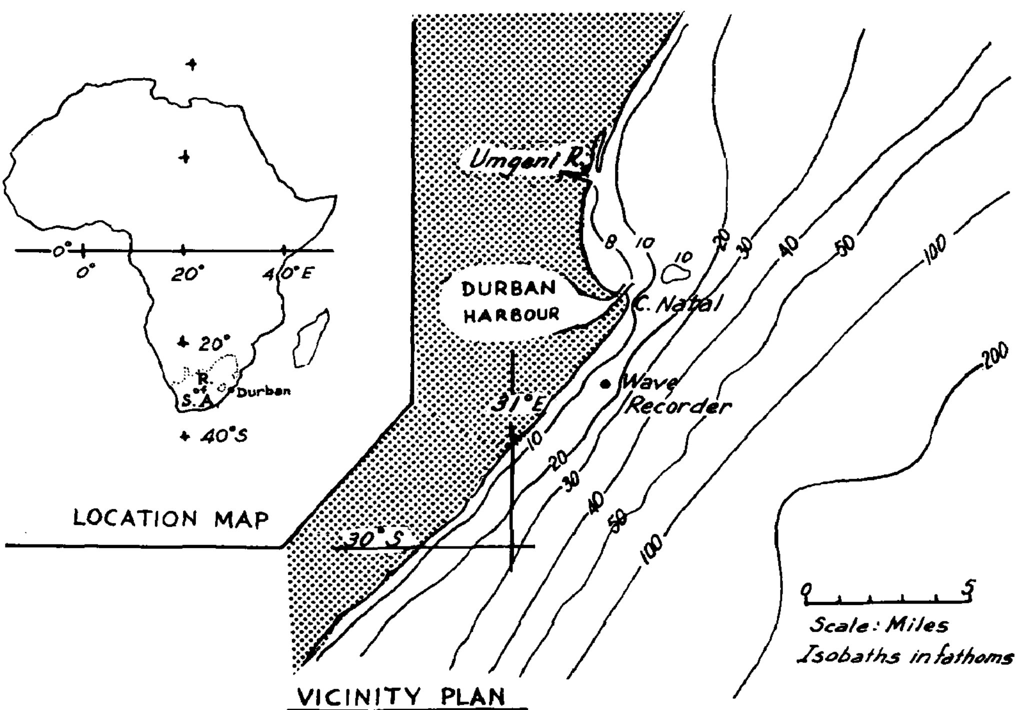


FIG. 1. — Vicinity and location map.

gentler offshore slope, while to the South the shore also becomes further removed from the limits of the continental shelf (100 fathom line). The site is thus on a line closest to deepwater conditions.

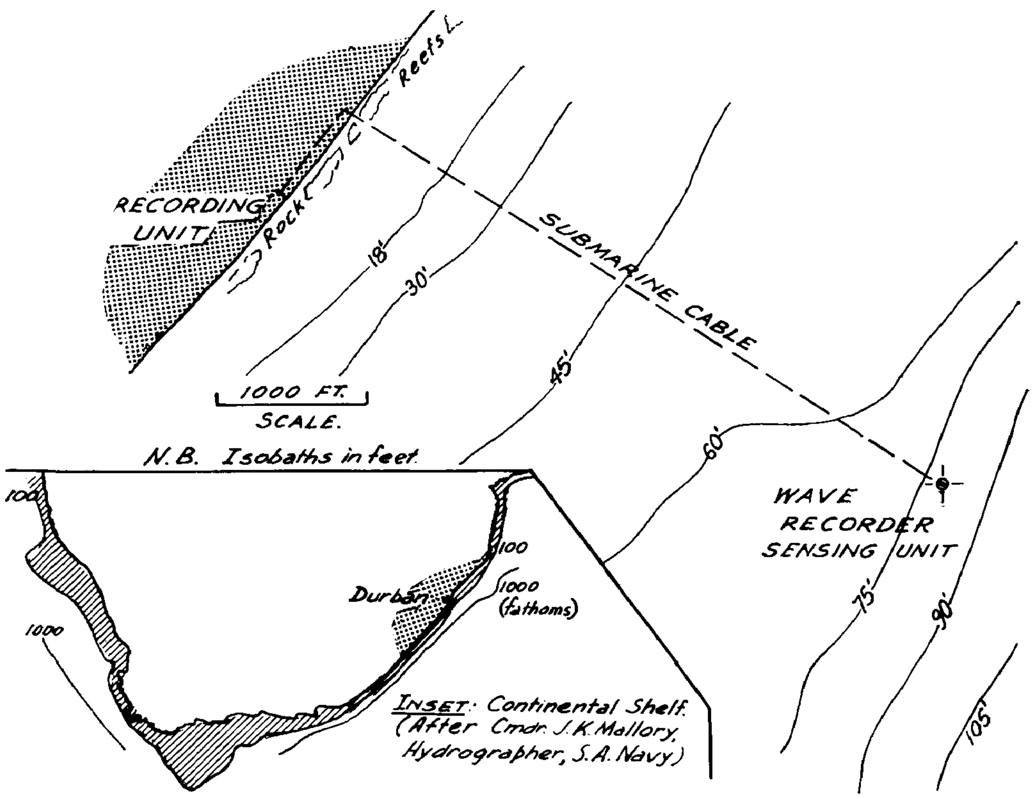


FIG. 2. — Relationship of wave recording site to continental shelf and nearshore isobaths.

The depth was chosen to be that at which a 6 second period wave just begins to be affected by the bottom. Waves of the type seen at Durban are basically of two types : short period storm-waves from NE and SW (six to eight seconds period) and long swells from E to SE of about 10 to 18 seconds period (Fig. 9). The six-second storm-wave has a wavelength of about 185 feet and would therefore just barely begin to be refracted by the bottom at a depth of half the wavelength, 92 ft. (The actual depth at the site is somewhat less: 76 to 82 feet depending on the tide). The long swells of, say, 12 second period, on the other hand, would have a wavelength of 750 ft and would, at this depth of approximately one tenth wavelength, already be propagated according to shallow-water wave theory. However, since the swells approach almost perpendicularly to the continental shelf and the nearshore isobaths, the swell would not be appreciably refracted in direction at the wave-recorder site and hence its energy content per foot width will not be materially affected. Although the 12 second swell's wave length will be slightly less, (600 ft), the periodicity is invariant and the wave height for the relatively low steepness of the swell still unchanged at the site.

The site chosen could therefore be considered an ideal one, representative of deepwater conditions for both swell and storm waves.

It was at first decided to place the transducers' axis of maximum sensitivity parallel to the coastline, so that the short storm waves, with their steeper slope and aerated crests, would be recorded with the maximum clarity while recording of the basic swell would be rather indifferent to transducer orientation due to the lesser wave slope.

ACTUAL PROCEDURE FOLLOWED IN PLACING OFFSHORE WAVE RECORDER AND LAYING 6000 FT LONG UNDERSEA CABLE

Summary

On the 29th November, 1961 the K-H wave recording transducer assembly was successfully placed in the sea at the planned location, about one mile off the Bluff, Durban, after the 6000 ft long undersea cable connection was laid from the shore-based recording apparatus to the transducer in 76 feet water depth.

Distinct but faint wave records were obtained at first (December 2, 1961) which established that instrument and cable were in functioning order but that further adjustments were necessary. Two divers were therefore sent out, on December 4th, to inspect the assembly on the sea bed. They found that the stand had inadvertently ended up on its side. It was righted and the steel cover plate, left on for protection of the transducer during the placing operation, was also removed. Wave recordings of great clarity were obtained thereafter, (Fig. 8).

Details

A great deal of preparation, briefing and preliminary trials and diving were undertaken to ensure a reasonable chance of success with the instrument and cable placing operation which was new to everyone concerned. The wave recorder transducer assembly was placed in a steel orientation box and is shown in Figs. 3 and 5. This box is resting on a turntable on a fourlegged stand, 6 ft high, designed to embed from a few inches to a few feet into the sand. The actual placing operation is portrayed in Figs. 3 and 4. The shore end of the cable, protected by polythene casing was routed through the surf and the gaps in the rocks by lifesavers and a hauling gang, while the sea end was taken by pilot boat to the instrument-and-stand assembly on a harbour craft from where it was lowered to the bottom. Great difficulty was experienced owing to a strong north-going current and the unarmoured submarine cable came close to snapping in the set of the current before the stand was finally down.

The results obtained when the recorder was subsequently switched on after connecting up were positive wave traces but somewhat faint. It was decided to risk disturbing the reasonably good operation for the sake of

FIG. 3. — The operation of laying the undersea cable from the shore towards the wave recorder position. (Transducer assembly in foreground; target markers on shore visible over bow of boat).

FIG. 4. — The stand carrying the transducer assembly, with cable connected, just before it was lowered from davits into 76 ft of water.

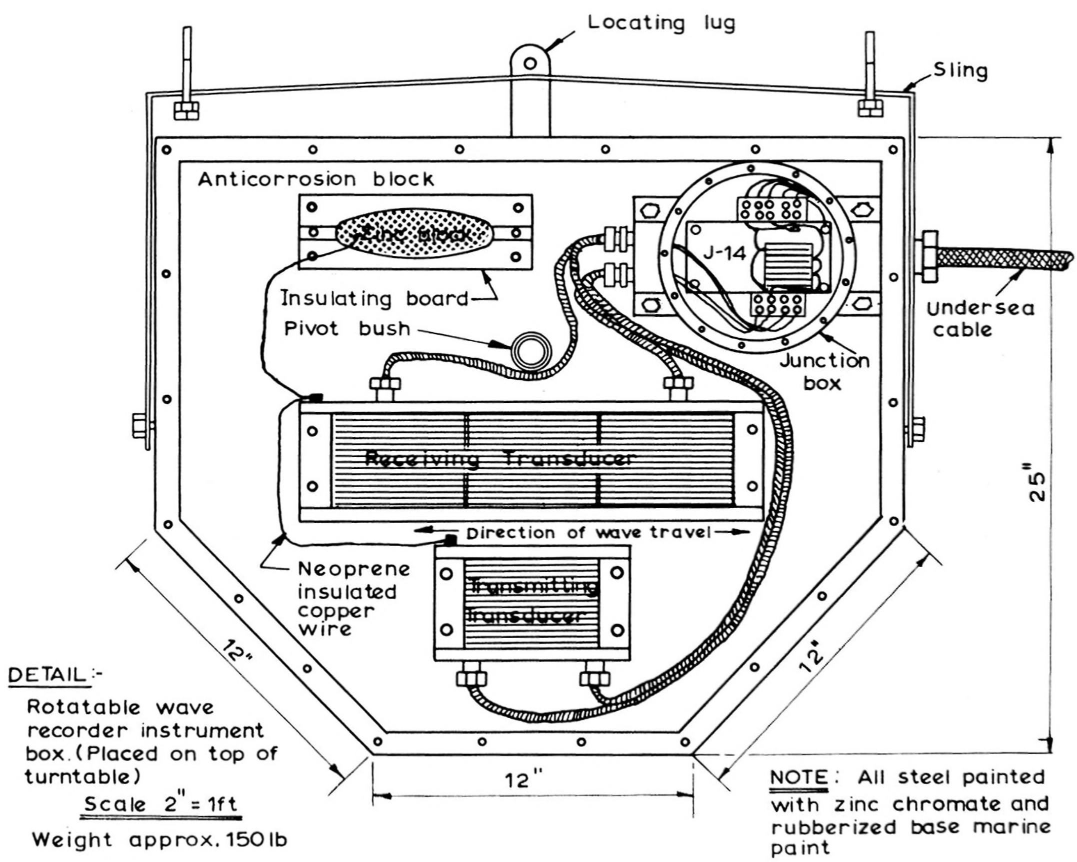


FIG. 5. — Details of the transducer assembly & housing as mounted on top of the stand (Figs. 3 & 4).

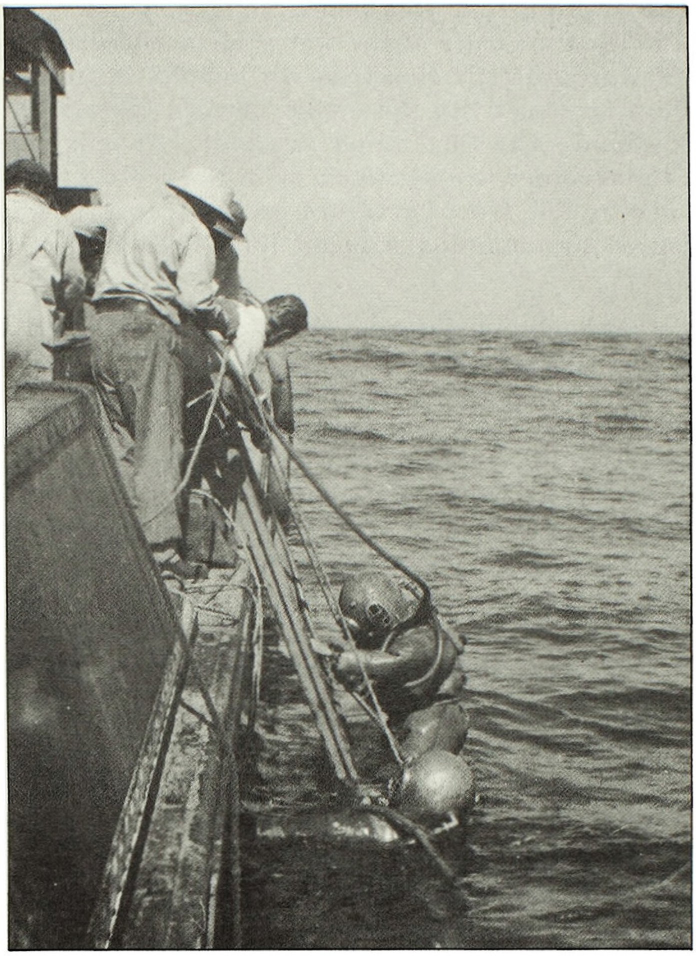


FIG. 6. — Divers going down to inspect and adjust stand two days after the recorder was placed.

getting something better. Two divers were, therefore, taken out to the site a few days later with the aim of removing the box cover plate purposely left on against damage of the transducers.

Considerable difficulties with anchoring close enough to the spot were encountered during this operation which lasted 10 hours and paid tribute to the endurance of the crew and personnel of the vessel used for the purpose. After their inspection the divers reported that the stand was found lying on its side.

The stand was then righted by winching and the box cover removed by one of the divers who reported that the desired horizontal attitude of the transducer box was obtained, but that the directional orientation was out by 90°. This was acceptable as, on second thoughts, it was considered to be of some advantage to favour the SE swell as far as sensitivity is concerned.

The wave records thereafter obtained were ideal and thus proved the suitability of the method. The sharpest "edge" in the records was obtained with long low swell; short storm waves showing long overlapping tails

(Fig. 8. *d*) due to multiple reflection points, but nevertheless a true envelope corresponding to the time trace of the water surface rise and fall. Breaking waves caused a degree of reflection from air bubbles in the top water levels but, by reducing the sensitivity the actual surface trace stood out sharply from the background. The tidal range is about 7 ft maximum, hence the wave trace on the recorder was set to occur in the central band of the paper so as not to have trouble from curvature on the trace. The change in tide could be measured by obtaining a mean line through the recorded wave traces.

The faint records obtained during the first trials showed a water depth of 83 feet, while subsequent to its readjustment the water depth was recorded at 77 feet (after making due allowance for the difference in tide). This difference of 6 feet is equal to the height of the stand, or the vertical change in elevation of the transducers with the setting upright of the stand the second time. This would indicate that the sounder was at first lying on its side when recording and hence it is capable of picking up the surface oscillations even when tilted 135° out of the horizontal plane, with a 1/4″ steel cover plate over the transducers as well. This result leads one to believe that the waves recorded now from the proper position are not likely to be subject to directional sensitivity of the transducers.

After about one month's operation the recorded signal strength dropped by about 50 %, possibly due to marine growth on the transducers but has since remained, with full gain, quite clear after an elapsed time of six months under water.

It was originally hoped to be able to obtain at least one year's data as to wave conditions off Durban. Recordings of 12 to 30 minutes duration were taken 4 times or fewer daily, depending on conditions, over a period of six months, with some short interruptions due to cable breaks in the surf zone, which began to occur during storms and high tides after 3 1/2 months trouble-free operation.

An extract of the information collected is presented for the first two week period which was analysed (Fig. 10). The paper speed is 8.2 inches per minute and the wave height scale is 10 ft = 1.16″ (See Fig. 8). Typical records for the various types of conditions prevailing off Durban were selected and 13 records, each of 468 sec. length were traced and one side blackened for harmonic analysis by the National Institute of Oceanography's wave analyser. The most significant frequencies and average wave heights were thus obtained (*). The analyses represent a fair reflection of the typical sea conditions encountered about one mile off the Bluff at Durban and are considered representative of the navigation conditions on the shelf which is about 10 miles wide.

(*) The assistance of Mrs. M. Darbyshire of N.I.O. in performing these analyses is gratefully acknowledged.

FEATURES OF INTEREST IN THE WAVE RECORDS

Definition under aerated conditions

There was no evidence of any actual breakers occurring over the recorder position but a choppy sea was recorded with good definition, appearing as a series of interlinked hyperbolas, with a well defined envelope giving the wave shape. Reflection off the aerated layer could be suppressed by lowering the gain until the surface trace showed up best.

Multiple traces

These provide an interesting independent way of measuring the wave length and can therefore be used with frequencies measured from the trace itself to determine the wave celerity, and thus for comparing the observed wave celerity for steep waves with the theoretical formulae for infinitesimal waves. (See Fig. *8d* and Appendix).

Peakedness

Referring to Fig. 7, it is seen that due to the non-verticality of the path of shortest distance to the water surface when parts of the wave other than the trough or crest is over the recorder the flanks are recorded

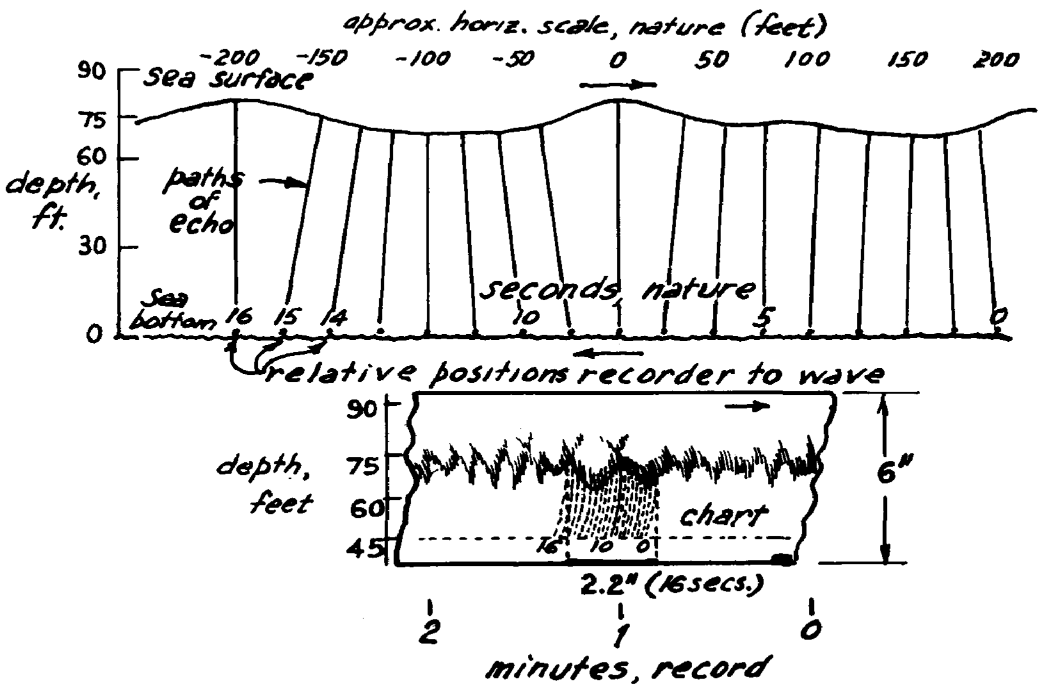


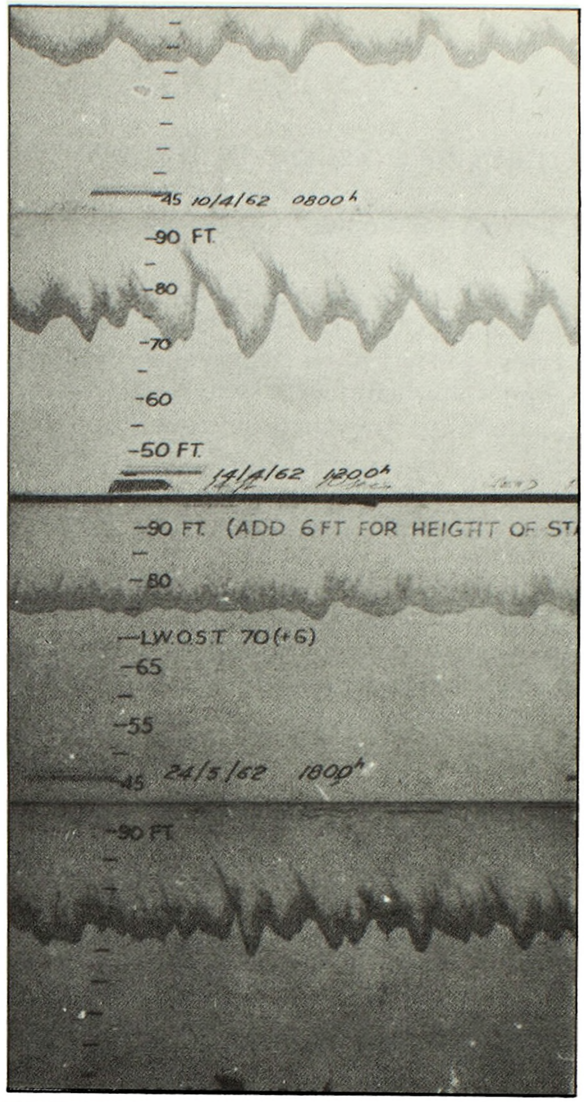
FIG. 7. — Definition sketch showing typical wave profile and corresponding echo trace obtained.

(a)

(b)

(c)

(d)



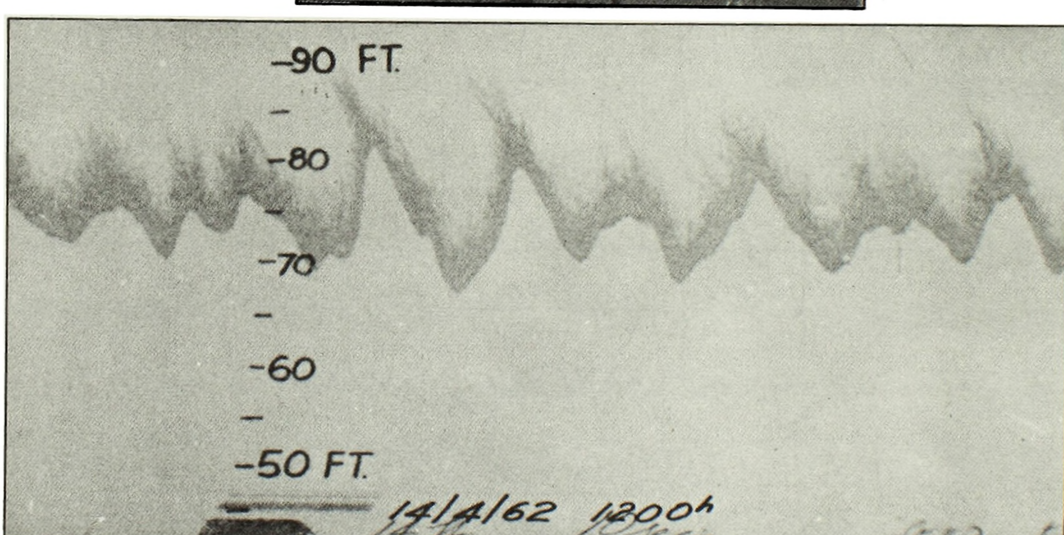


FIG. 8. — Sample traces obtained of various typical wave conditions.
(*a*) Medium, long swell
(*b*) High, short swell
(*c*) Calm sea
(*d*) Storm waves
(*e*) Close up of (*b*)

slightly low. True wave form can therefore not be obtained directly from the chart but can quite easily be constructed by swinging an arc for each sounding (533/min) along an extended time base and connecting the arcs by a smooth envelope (Fig. 7). This is a time base record and is generally not the same as the instantaneous distance-base wave form. Where a piece of wave record of several very uniform oscillations is occasionally found, all its wave crests and troughs will have travelled with almost uniform calculable speed and a corrected time-base trace will also give a fairly accurate vertical section through the waves. Provided the wave recorder is placed not too deep (76 ft is considered to be about ideal) so that it is not below the centre of curvature of the crest of the shortest wave desired to record, the crest of the wave will be closer than the flanks at the instant the crest passes over, therefore true vertical wave heights will be recorded in spite of the distortion of the wave sides.

Accuracy

The instrument was calibrated prior to its installation by operating with the transducers in a vertical plane, held against the sides in a tank of water 20 ft square. Traces were obtained at 20, 40, 60, etc., feet intervals across the chart, due to the repeated reflections from the opposite sides, proving that there was no misreading or errors involved. The depth at the point of placing was line-sounded at 78 ft $\pm$ 1 ft and (inverted) echo-sounded at 76 ft. The tidal range as read from the echo traces at 6 hour intervals agreed with the tide-tables. The accuracy with which each wave is recorded can be seen from the clear line of the trace and is of the order of 1/4 ft in 10 ft, or better (Fig. 8).

CHARACTERISTICS OF RECORDED WAVES OFF DURBAN

The wave-parameters of interest in engineering aspects are maximum and significant wave height, dominant periodicities and mean energy. The maximum wave height (or highest wave recorded in the recording interval of 12 minutes) was the easiest to obtain from the records while the other quantities involved hand integration or harmonic analysis.

Typical values for part of a month are given in Fig. 10.

The highest waves actually recorded were 15 and 16 feet (on two or three occasions), the general storm wave being about 10 to 12 feet (significant height) at 6 to 8 seconds period (Fig. 8*d*) and the average normal sea condition about 4 1/2 ft (significant height). Periodicities vary widely between 5 seconds and 18 seconds, the latter associated with tropical Indian ocean cyclones. The energy-richest condition observed was a 11 to 15 ft swell and storm wave combination with dominant periodicities of 15 and 10 seconds respectively. (Fig. 8*b*). Wave energies varied between 360 HP per foot of wave crest or coastline and 5 HP, the latter associated with remarkably calm conditions of 2 to 3 ft waves lasting for several days (Fig. 8*c*).

In Fig. 9 is shown a directional frequency spectrum as obtained from visual observation records, supplementing the height-periodicity information obtained by the echo-recorder. This shows that most of the long-

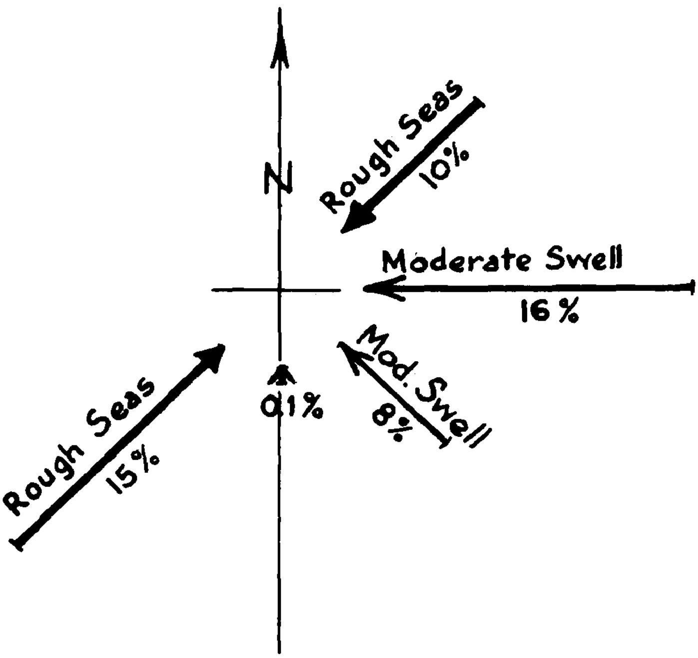


FIG. 9. — Directional distribution of sea and swell off Durban (from another source).

period swell approaches from an east to south-easterly direction, while the short period storm waves run more nearly parallel to the coast as do the predominant winds.

CONCLUSIONS — ADVANTAGES AND DISADVANTAGES

The main advantage that has been found of the inverted echo-sounder wave recorder over other types of wave recorder (such as pressure devices) is that it gives a direct and clear wave trace that is linearly proportional to the actual water surface motion. The analysis of frequency requires a harmonic analyser device, but for practical purposes a set of lines ruled at various intervals can be used to determine average periods quickly. The statistical data presented were determined by counting the number of zero crossings and measuring of each wave height in a 5 minute period and agreed well with the exact harmonic analyses made for particular records.

The second advantage is that of stability. The modulation depends solely on the velocity of sound in water and, for wave work, this can be treated as invariant from its value for the average temperature - salinity conditions. Deterioration of cable or transducers may affect the clarity of signal but not its modulation — a difficulty encountered with piezo-

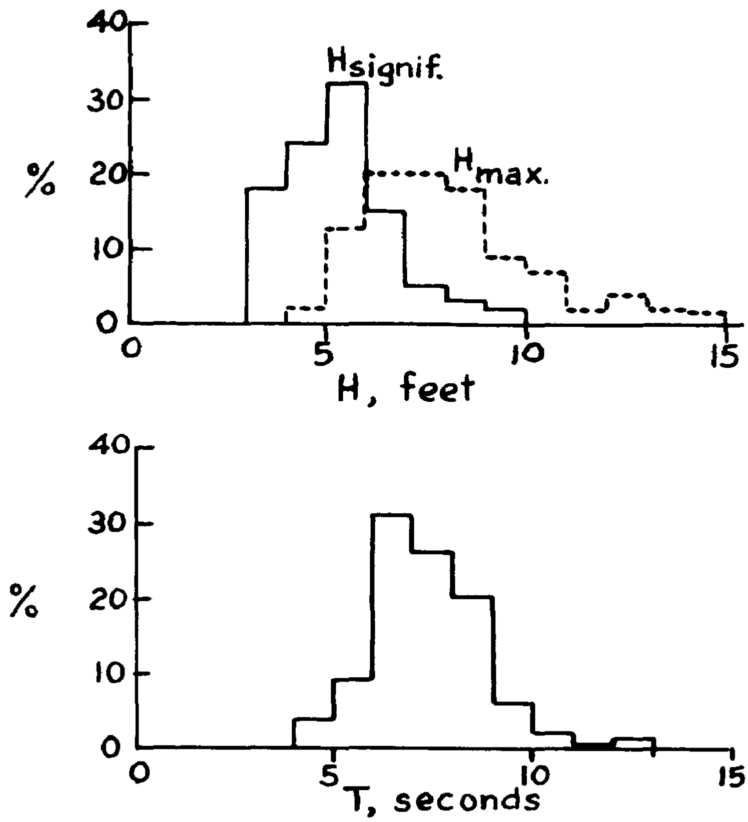


FIG. 10. — Frequency distribution obtained of significant wave height and dominant period off Durban for typical fortnightly period.

electric, pressure and capacitance type recorders. No trouble with the acoustic transducers was experienced for a period of six months in open ocean conditions. They were cathodically protected by means of a special type zinc anti-corrosion block, containing aluminium and silicon (*).

A disadvantage with this type of wave recorder, as well as with all other single-position recorders, is that wave approach direction is not recorded. This can be overcome, as in the present case, by measuring wave direction simultaneously from the shore recording station or a nearby vantage point by means of a protractor and peep sights, theodolite or similar device and writing in on the recorder chart the direction from which the waves seem to approach. In the present case a series of 5 sets of aerial photographs of swell and storm waves from various directions were obtained as well. One practical disadvantage of the present installation

(*) The advice and help of Cmdr. W. J. COPENHAGEN, O.B.E., of the C.S.I.R. Corrosion Unit, is gratefully acknowledged.

bears mentioning, namely the vulnerability of the five core (unarmoured) submarine cable in the surf zone. A length of 500 ft of armoured cable would, if available, have been a better choice for the surf-zone crossing, as repeated cable repairs have become necessary after an initial three and a half months' period of trouble-free operation.

Barring the difficulties with the cable, the venture can be judged as very successful, in that it has thus far recorded a representative sample of six months' wave conditions off Durban, sufficient for the requirements of the further analysis of the local sand movement problems.

ACKNOWLEDGEMENTS

The experience dealt with in this paper was gained as part of a coastal engineering investigation on behalf of the South African Railways Administration and the City Council of Durban. Their permission to publish this paper is gratefully acknowledged.

Messrs. Kelvin and Hughes, Ltd., London and Messrs. G. H. Langler and Co. Durban, are thanked for their advice and assistance with practical problems.

REFERENCES

[1] Krause, D. C. : " Interpretation of Echo Sounding Profiles ". *International Hydrographic Review,* Vol. XXXIX, No. 1, Jan. 1962, p. 65.

[2] Tucker, M. J. : " Sea-Wave Recording ", the Dock and Harbour Authority, No. 397, Vol. 34, November 1953, p. 207.

[3] Private Communication, Messrs. Kelvin and Hughes, Ltd.

APPENDIX

Method of measuring wave length (and celerity) with an inverted echo-sounder wave recorder

The following analysis can be performed on the records where the echo trace show long overlapping hyperbolic " tails ". This is generally only found for stormy conditions where the waves are steep enough to create multiple echoes. The echo-sounder transducers have to be placed sufficiently deep below the surface, e.g. 75 feet, to receive multiple echoes.

Fig. 11 is the definition sketch showing relative position of storm wave and echo sounder at three time intervals spaced one-half the dominant wave period apart.

In this figure, knowing a, $b_1 = b_2$ and h or e, then L can be derived and hence, from L and periodicity, the celerity C. The overlapping traces on the recording paper, yield these values as shown in Fig. 12, which is the corresponding echo trace as it appears (on low sensitivity) for a short steep storm wave.

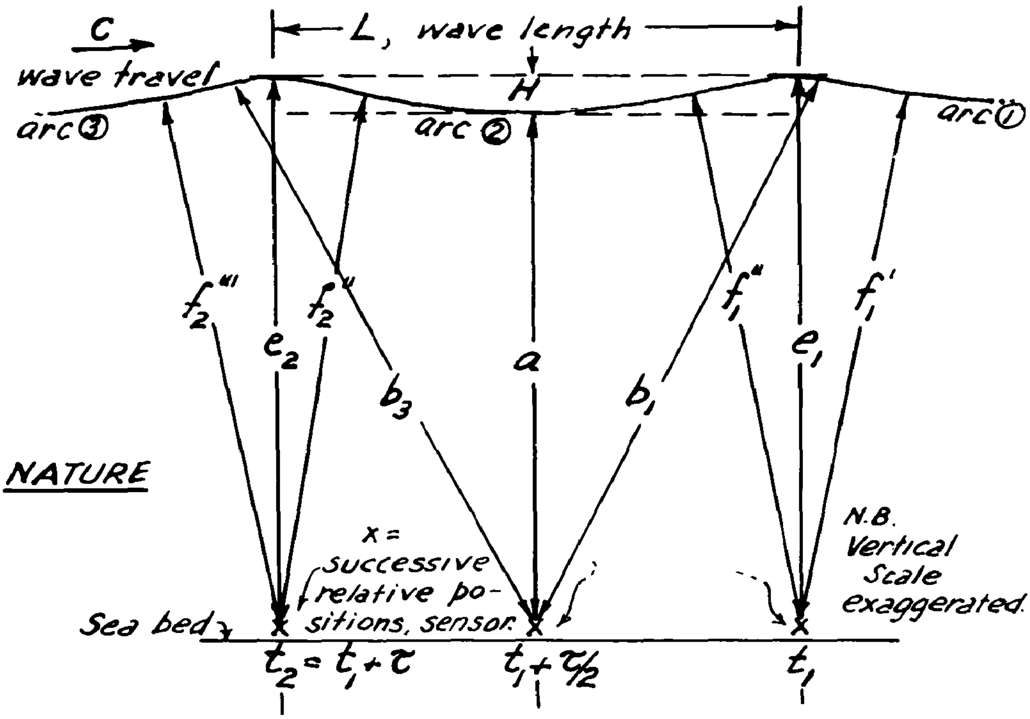


FIG. 11. — Nature.

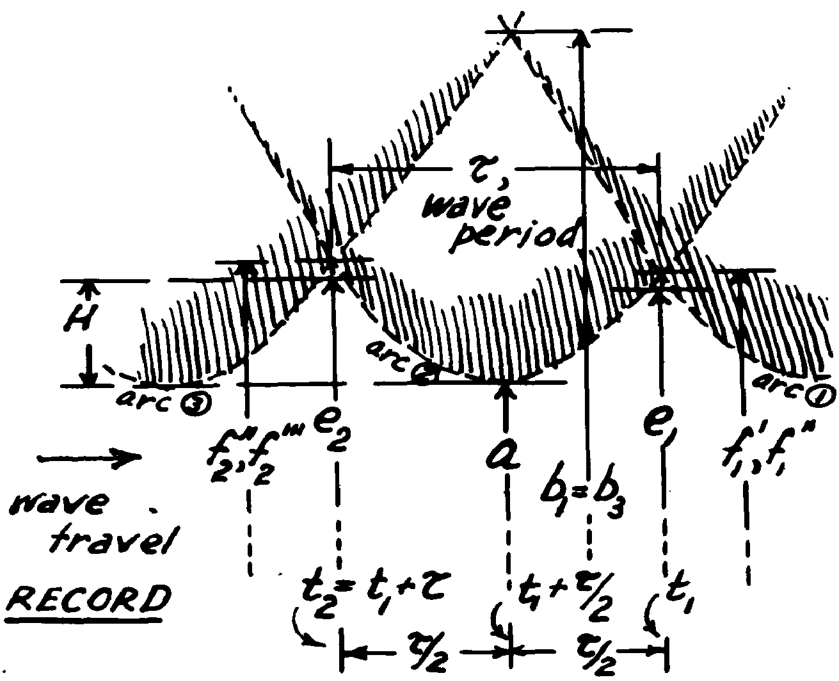


FIG. 12. — Record.

Method

Select a portion of a record showing overlapping traces as above, where a regular uniform train, of 3 or 4 waves in succession, appears.

Measure a, b and e_{avg} for each pair for adjacent crests and calculate $L = 2(b^2 - e^2)^{1/2}$, τ and hence $C = L/\tau$.

The values of τ and L thus obtained may be checked against the solution for (theoretical) :

$$\tau = (2\pi L)^{1/2} \left(g \tan h \frac{2\pi y}{L} \right)^{-\frac{1}{2}}$$