A CONSIDERATION OF WHETHER CHARTS SHOULD SHOW ECHO-SOUNDER DEPTHS UNCORRECTED FOR THE VARYING SPEED OF SOUND IN SEA WATER

by D.W. NEWSON
Hydrographic Department of Great Britain

INTRODUCTION

At its meeting in Monaco in April 1969, the Commission for the International Chart decided to recommend to the International Hydrographic Bureau that uncorrected echo-sounder depths be shown on charts of the new series, no attempt being made to apply corrections beyond the 200-metre contour for the varying velocity of sound in sea water. This decision ran contrary to present IHB policy, as recorded in B 185 of the Repertory of Technical Resolutions. The time would therefore seem to have arrived to look again at this policy in the light of current thinking. The present notes, without claiming to be exhaustive, seek to record arguments for and against uncorrected and corrected soundings, without, however, attempting to record a conclusion in favour of one or the other. Any opinions expressed are those of the author, and do not necessarily represent the views of the Hydrographic Department of Great Britain.

The argument with which this paper is concerned represents the revival of an old and often repeated question, first discussed at the 2nd International Hydrographic Conference of 1929: should echo-sounder depths obtained in the deep oceans, in 200 metres or more of water, be corrected so as to convert them as nearly as possible to true depths, before they are inserted on nautical charts? The 1929 conference accepted the principle of correction, though the opposite point of view was strongly expressed. At that time, echo-sounding was in its infancy and still somewhat suspect, and the great majority of soundings shown on charts were true depths which had been obtained with lead-lines. In 1947 it was resolved to use Matthews' Tables (British Admiralty Publication HD 282) to obtain international uniformity when correcting depths. The associated question of standardising on a particular velocity for the calibration of echo-sounders was argued at several conferences, 1 500 metres/second (820 fathoms/second) being adopted by the 1962 conference in preference to 1 463

metres/second (800 fathoms/second). Of these two speeds, the one chosen is almost always nearer to the actual speed of sound through sea water. These various decisions are recorded in B 184 and B 185 of the Repertory of Technical Resolutions (6th Edition 1965). However, the policies they represent are not implemented by all members of the IHB.

Other recent developments have also revived interest in the debate for and against correcting echo-soundings. Precision Depth Recorders (PDR) are now available for use by both surveyors and navigators, and methods which will replace linear sounding by measuring depths along belts or over areas are at hand — but these techniques are not yet matched by high-accuracy correction tables of sound velocities. The idea of navigation by depth in mid-ocean — for which a new US chart series specifically caters — seems to be feasible. Scientific and commercial interest in the oceans is increasing rapidly, and it is arguable that nautical charts should cater also for needs such as these. Against all these new developments, however, must be set the traditional role which the nautical chart plays in the hands of the navigator.

VARIATIONS IN NATIONAL PRACTICE

A comprehensive statement on the way member countries comply with the relevant parts of Technical Resolutions B 184 and B 185 was included in an article by VIGLIERI in the *International Hydrographic Review* in 1953 [1]. It set out the answers received from twenty-one nations to a questionnaire put by the IHB, though unfortunately not all the questions were in fact answered. However, in respect of the principles with which we are at present concerned, it was found that a majority of countries did conform to IHB policy. Of the nineteen countries conducting surveys in the open sea, eleven applied sound velocity corrections before charting soundings, the limit beyond which they were applied ranging from 100 to 300 metres in depth. Ten of the nineteen used Matthews' Tables — including a Netherlands version based on them — while Japan preferred Kuwahara's tables, and Germany used Dietrich's tables in the North Sea and Baltic in lieu of Matthews'. As regards the velocity of sound adopted for echo-sounder calibration, sixteen nations out of twenty-one reported that 1 500 metres/second was their standard, though five of them also used a second velocity. Six different velocities were in use: 1 450, 1 463, 1 464, 1 480, 1 500 and 1 600 metres/second. No replies at all were received at the time from eight other hydrographic offices.

VALIDITY OF CONCEPT OF "CORRECTED" DEPTHS

Modern PDRs are capable of the exceedingly high level of accuracy of 1 fathom in 3 000 fathoms [2] provided they are properly maintained. But

it is first necessary to consider, what quantity is it exactly that the PDR, or conventional echo-sounder, is measuring? and secondly, how precisely can these measurements be converted into "true" depths of the ocean floor? These are obviously vital questions, both for the surveyors and compilers who are responsible for the data which appears on charts, and for the navigators who make use of them.

Various writers have comprehensively treated the geometry of echo-traces, from DE VANSSAY DE BLAVOUS in 1930 [3] to KRAUSE in 1962 [4]. They have shown that, for various reasons, the echo-trace often does not give a true picture of the sea bottom, either as regards depth, or shape. As is well known, the dominant echo is returned from the point nearest the ship: if the bottom slopes, this point is upslope of the ship's position, not vertically beneath it, and less water is shown beneath the ship than there really is. But SHALOWITZ has shown [5] that on ocean chart scales the position errors involved — and, by analogy, the depth errors — are quite insignificant for practical navigational purposes, and so may be ignored when soundings are plotted on small-scale charts. For example, on a chart at the scale of 1/1 million, an extreme depth of 11 000 metres, lying on a steep gradient of 40°, would be displaced by only 4 millimetres. In reality, almost 99% of the total area of the oceans is less than 6 000 metres in depth, and slopes are, in the main, comparatively gentle. SHALOWITZ's conclusion therefore holds good, especially when it is remembered that surveyors' and navigators' PDRs and echo-sounders are equally subject to the effect of slope — a second ship may pass by a seamount at the same range as the ship which first reported it, and record the same depth, but it may be on a totally different track. In practice, it is obviously immaterial if the depth is charted very slightly out of its true position.

Should the objective be absolute scientific truth, then the corrections for slope described by DE VANSSAY de BLAVOUS in his later paper [6] would need to be made. Even so, a true representation in all respects of the ocean bed would not be obtainable [4]. Slopes are shown on echo-traces as having gentler gradients than is really the case, and projections of various configurations and degrees of ruggedness are represented almost universally in the form of hyperbolae, the characteristic geometric shape of echo-traces — though a graphical method has been devised for reconstructing the true shapes of certain breaks in slope which produce hyperbolae [7]. Fortunately, the minimum depth is recorded when a sounding vessel passes directly over a seamount; but certain trenches and troughs are almost eliminated on echo-traces, or made to appear shallower than they really are, or different in shape. In such cases, or where the gradient is changing irregularly, there is no possibility of rectifying the echo-trace. Absolute scientific truth is not, in fact, always obtainable using normal echo-sounding methods. Narrow-beam, stabilised, directional sets come nearest to eliminating slope effect, and representing true forms, but they are most suited to detailed surveys of small areas, at moderate depth [8]. To detect most completely the shape of the sea floor, additional sideways-looking transducers are required [9].

Of the minor factors influencing the accuracy of echo-traces, KRAUSE found in general that the effect of the forward motion of ships — causing

an echo to be received in a different position from where the pulse was transmitted — was negligible, as was the refraction of the sound ray due to variations in the sound velocity structure of sea water. The effects of swell and heavy seas, variables which cannot be eliminated, should also be mentioned.

Having explored some of the limitations inherent in acoustic measurement of depth, the next point to consider is the accuracy of the corrections applied to convert echo-sounder depths to "true" depths — how true is "true"? As already mentioned, several sets of correction tables are in existence — thereby potentially leading to slight differences in value due to the correction process itself — but Technical Resolution B 185 specifies the use of Matthews' Tables for this purpose, and these will therefore be considered.

As regards the magnitude of the corrections in Matthews' Tables, the largest lies in Area 41 and is an increment of 319 metres at a depth of 10 000 metres, for echo-sounders calibrated at 1 500 metres/second. To a navigator fixing his position by soundings over a part of the sea-bed where the slope is 1°, and neglecting to correct his echo-sounder readings to obtain compatibility with his chart, this increment could represent a position error of over 18 200 metres. At 25°, the difference would be 684 metres. A less extreme Matthews correction of 50 metres would be equivalent to an apparent position shift of about 2 850 metres on a 1° slope, or 107 metres at 25°. At a chart scale of 1/1 million, these position differences would measure 18, 0.7, 3 and 0.1 millimetres respectively. Clearly, serious inconsistencies could result from mixing corrected and uncorrected soundings on the same chart.

Recent calculations, by CHARNOCK and CREASE [10], using Wilson's sound velocity formulae with extensive modern observations of temperature and salinity, have shown that the use of Matthews' Tables in the Mediterranean leads to errors in depth of 3 metres at the most. But such errors must be larger in areas where oceanographic observations were, and may still be, comparatively scanty — an error of 25 metres in a depth of 5 000 metres has been demonstrated in Area 9 [11]. Another effect of the arrangement of Matthews' Tables into 52 separate oceanic areas is seen in the artificial "steps" in ocean bottom topography, due to the use of different tables each side of area boundaries : there is a maximum discontinuity of 15 metres.

Taking temperature variations in the upper layers into account, the same writers have shown that it would be possible to produce new tables of the Mediterranean — admittedly a comparatively stable area oceanographically — which would enable echo-depths to be converted to true depths with an accuracy of 1 metre. But conventional tables, aiming at a similar degree of accuracy, covering the whole world, would be extremely bulky, and the suggestion is therefore made for a computer-compatible, diagrammatic lay-out which would also avoid the inaccuracies inherent in the Matthews system of rigid oceanic areas. Any new tables must still reflect to an extent, in the accuracy they achieve, the uneven spread of oceanographic data across the world. A further complication lies in time-variations in the sound velocity structure, due to seasonal or short-term

local changes in temperature or salinity — but it has been estimated that 3 metres would normally be the maximum depth error due to this cause, and less than 10 metres in areas of meandering currents such as the Gulf Stream [9]. For convenience in comparing his echo-sounder depths with corrected charted depths, the navigator would still require conventional-style tables, but to be manageable, they would have to depend on a lower order of accuracy, say 5 metres. For these various reasons, exact comparisons with charted depths would not be possible, though they would usually be very close, and quite compatible with the effective level of accuracy obtainable with ships' echo-sounders (as previously described) and position-fixing techniques.

As a last point, in this consideration of the accuracy of echo-depths on charts, it may be recalled that not even the old lead-line depths, many of which are of necessity retained on ocean charts, can be guaranteed as completely "true" depths, as it must have been rare for the sounding wires to be truly vertical along their entire length.

THE NEEDS OF THE NAVIGATOR

From the navigator's viewpoint the chief advantage in charting uncorrected depths must lie in being able — within the limitations already mentioned — to compare charted soundings directly with the depths recorded by his echo-sounder. This facilitates navigation by depth alone and provides a useful adjunct to *per se* position-fixing methods, or perhaps an alternative to them in the event of overcast skies or malfunctioning of sophisticated electronic systems. Should shipping in the future take to passing under the sea rather than on it, then the capacity rapidly to compare depths on charts and echo-traces could well become very important. But as a first step, international standardisation of the velocity of sound used both for charts and for echo-sounders would be imperative, as whenever these differed, depths would have to be converted, if not corrected, before a comparison could be made.

It may be argued, that for navigators — many of whom switch off their echo-sounders altogether outside the 200 metre line — position-fixing by depth will always be a poor substitute for purpose-built systems, and that the future would seem to lie in better and cheaper hyperbolic or satellite methods. For a system dependent on depths to be reasonably precise, all ships would have to carry PDRs, and the accuracy of nautical charts of the oceans would have to be considerably improved. On a typical 1/3 500 000 chart, a four-figure sounding covers an area of about 100 square kilometres, and its position could be anywhere in a twenty square-kilometre area, while the chance of actually passing over any charted sounding is very slight. Such charts are usually based on sporadic lines of passage soundings, of variable vertical and horizontal accuracy, and the depth contours they show are few and usually only approximate. However, improvements in these respects may be attainable, as will be mentioned below.

It is presumed that on the Continental Shelf — say to the 200 metre line — it would still be desired to chart true depths. A small complication would therefore arise at the junction with uncorrected depths. However, according to Matthews' Tables the discontinuity would nowhere exceed 8 metres, assuming a standard sound velocity of 1 500 metres/second.

STANDPOINT OF HYDROGRAPHIC OFFICES

Correcting soundings afloat or ashore is a laborious task, and those hydrographic offices which do so would be saved the trouble if they reversed their present policies. They would then be faced with the task of "de-correcting" the depths on their existing chart series, and the magnitude of this in effort and time needs no stating. Most charts of the deep ocean, whether produced by offices following a policy of true or of uncorrected depths, of necessity carry a mixture of soundings on both systems, due to uncertainty as to the system followed on some of the original material used. Clearly it would be wrong in such circumstances to de-correct all soundings indiscriminately — many of the older data, too, may well be suspect as regards both depth and position, and therefore not worth the trouble. The best solution might lie in de-correcting existing soundings only if known to be sufficiently reliable (e.g. PDR) though all new data would, of course, be charted uncorrected from the outset. Eventually whole charts would be covered with high-quality depths corresponding to echo-sounder readings, but until this were so it would help the navigator, and the chart compiler, if the more doubtful soundings were entered in a different style. However, it must be emphasised that the saving of effort, eventually resulting from a change to charting uncorrected depths, would be reduced unless this were the universal practice, so that all data incoming to an office, from whatever source, was in this form.

Changing survey methods are another factor of great importance to the argument, especially the introduction of multi-sensor depth-measuring equipment — enabling the simultaneous sounding of broad swathes of the sea bed, instead of mere lines — and of ship-borne automated data-loggers and plotters. It is becoming possible to produce, entirely automatically, fair sheets of the ocean floor, complete with depth contours at as fine an interval as is required — a far cry from the random lines of passage soundings on which ocean charts have for so long depended. No doubt a ship-board computer could be programmed to convert its data to "true" depths prior to plotting, but whether sufficient world-wide oceanographic observations yet exist, to enable the accuracy of the corrections to be at all times as great as that of the depths obtained by the new methods, is uncertain. The continuing process of refining these corrections can, indeed, be regarded as an argument against making them at all. Clearly, as soon as any appreciable quantity of ocean surveys have been carried out using these modern methods, nautical charts based on them can only follow them as regards true or uncorrected depths, and also as regards the velocity of sound

assumed, 1 463 or 1 500 metres/second. The alternative would be a truly enormous task of conversion of contours and depths. This must be a powerful factor in the present discussion.

As already indicated, the traditional style of nautical charts does not lend itself to navigation by depth. To this end, the HO/BC series of the U.S. Naval Oceanographic Office [12], planned to cover the waters off a large part of the world's coasts on a scale of approximately 1/1 million, have depth curves at an interval of 100 fathoms down to the greatest depths, with little sign of generalisation. The recommended method of use is to plot a section of a ship's track at chart scale, on a transparent overlay, with the PDR depth noted at time intervals of 10 minutes or so; then by matching the overlay with the charted contours, the ship's position at the most recent time noted may be determined. Any nautical chart, which it may be desired to make suitable for true navigation by depth, would have to follow this "bathymetric" style, with frequent contours based on uncorrected soundings. But as long as such contours have to be interpolated from sporadic passage soundings, they can only be approximate; only comparatively large-scale charts based on modern comprehensive surveys, such as are postulated in the previous paragraph, would permit consistently accurate navigation by depth.

For hydrographic offices which at present chart corrected depths, it is obviously convenient to record ocean soundings which they collect for the IHB's GEBCO series — and also use on their own small-scale nautical charts, and probably in other ways — in corrected form on their master plotting sheets. If such offices should change to a policy of uncorrected soundings on their nautical charts, they would for their own convenience be inclined to make their ocean sounding collector sheets conform. The conversion would be another considerable task, and they would be unlikely to have the resources to maintain a parallel set of sheets of "true" depths specially for GEBCO.

THE NEEDS OF OTHER CHART USERS

Sea charts are primarily navigational tools and the needs of the mariner are, and are likely to remain, paramount. However, with the oceanographic explosion upon us, it is likely that other classes of user will feel an increasing need for maps of the sea, just as land maps are now put to many more uses than their original ones. Ocean scientists of various disciplines reputedly prefer bathymetric charts of the oceans which show true depths — though CREASE *et al.* [9] stress that charts of true bathymetry can only be produced for closely sounded areas well covered with oceanographic observations. GEBCO is an example of a bathymetric chart which aims to depict true depths; no doubt small-scale nautical charts, if as detailed as the U.S. HO/BC series, would also be of great interest to the scientific community. But for commercial exploitation of small areas of the ocean bed, engineers will probably make their own large-scale surveys; in such

cases relative changes in level are often the main interest, and the question of correcting depth is unimportant. Comparative newcomers to the community of chart users are international lawyers, starting with the determination of national fishing limits, and now concerned with devising limits of interest for the exploitation of the resources of the ocean floor. For them, any consistent criterion, whether "true" depths, or uncorrected depths based on a standard velocity of sound, would appear to be highly desirable, and surely must be an improvement on the present variations between different nations' charts.

CONCLUSION : TWO VITAL QUESTIONS

The problem with which this paper is concerned was debated at the 1952 International Hydrographic Conference, and two quotations from the Report of Proceedings point, in the view of the writer, to the fundamental questions. Dr BOHNECKE of Germany said, firstly, that "it was important to know if the object was to work on behalf of navigators or to give an exact picture of the bottom of the sea". Would a universal policy of charting depth values which could be directly compared with depth recorders be a definite advantage to mariners, or would they make much use of this as a navigational method ? Alternatively, should the chief objective be scientific truth — but does this presuppose a greater accuracy in the technique of echo-sounding, and in converting echo-depths to true depths, than is obtainable ? Clearly the views of navigators and other chart users should be sought.

The second question was posed by Vice Admiral DAY of Great Britain, that "it was possible that in the future sounding methods might exist by totally different procedures and this would entail a certain measure of confusion unless a standard method of showing actual depth had been used". Admittedly the corrections needed to produce "true" depths are subject to refinement — but true depths are the only absolute criterion which is independent of the method of measurement. It is conceivable that new sensors might eventually be developed to enable the sound velocity structure of the sea beneath the ship to be determined simultaneously with the emission of the sound pulse, the travel time of which could thereby be automatically adjusted; or perhaps a non-acoustic method of depth measurement, immune from the varying effect of sea water on sound waves, might come in the future. A modern solution to this problem, by whatever means, would be a signal contribution to the science of hydrography.

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