

ON THE ACCURACY OF CONFIGURATION OF SEA BOTTOM PROFILES WITH HIGH FREQUENCY ECHO SOUNDERS

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The introduction of high frequency echo sounders with recorders in German river and sea surveying during recent years has resulted in knowledge of a number of facts that may be utilized for the solution of the much discussed problem of the true depth and the accuracy of configuration of irregular sections of the ocean bottom. The determination of what is called the slope error and the recognition of cross-over effect are tasks with which many surveying experts have been dealing ever since the introduction of echo sounding, and a series of valuable papers are the result. (See (1), (2), (3), (4), (5). Our experiments for the time being are restricted to the use of less concentrated cones of the equipment and to the surveying of depths not exceeding about 700 metres.

The decisive difficulty of the problem rests with the fact that surfaces of the sea bottom are scanned by the spherical caps of sound pulses, while in the case of hand-operated leads, only points are sounded. One should, however, not overlook the fact that the new method of sounding has a number of advantages. I only wish to mention the advantage that the depths measured are no longer for individual points but for a continuous, more or less wide track of the least depths below the ship's track. The width of the track is dependent on the depth and is marked by the characteristic line of the arrangement of the oscillators which may also be called the effective range of the instrument. Within this range values representing equal transmitting times lie on a spherical cap. As a result points lying at the same depth are shown with different times of transmission - i.e. on the echogram they appear at various depths - if they are sounded at various angles with respect to the perpendicular. In order to counteract the influence of such errors in recording which, in the case of irregular profiles, give a wrong picture both to the surveying expert and to the geographer, the diameter of the effective range can be reduced by a greater concentration of the radiating cones. This possibility is, however, limited from the ship-builder's point of view, if the conventional sonic frequencies are applied, and limited by the increasing absorption of sound in the water, and accordingly by the reduction of the depth to be obtained, if higher frequencies are involved.

The recording apparatus of echo sounders which are at present used in Germany, will record all echoes from surface elements of the sea bottom which are covered by the effective cone of the equipment in the correct

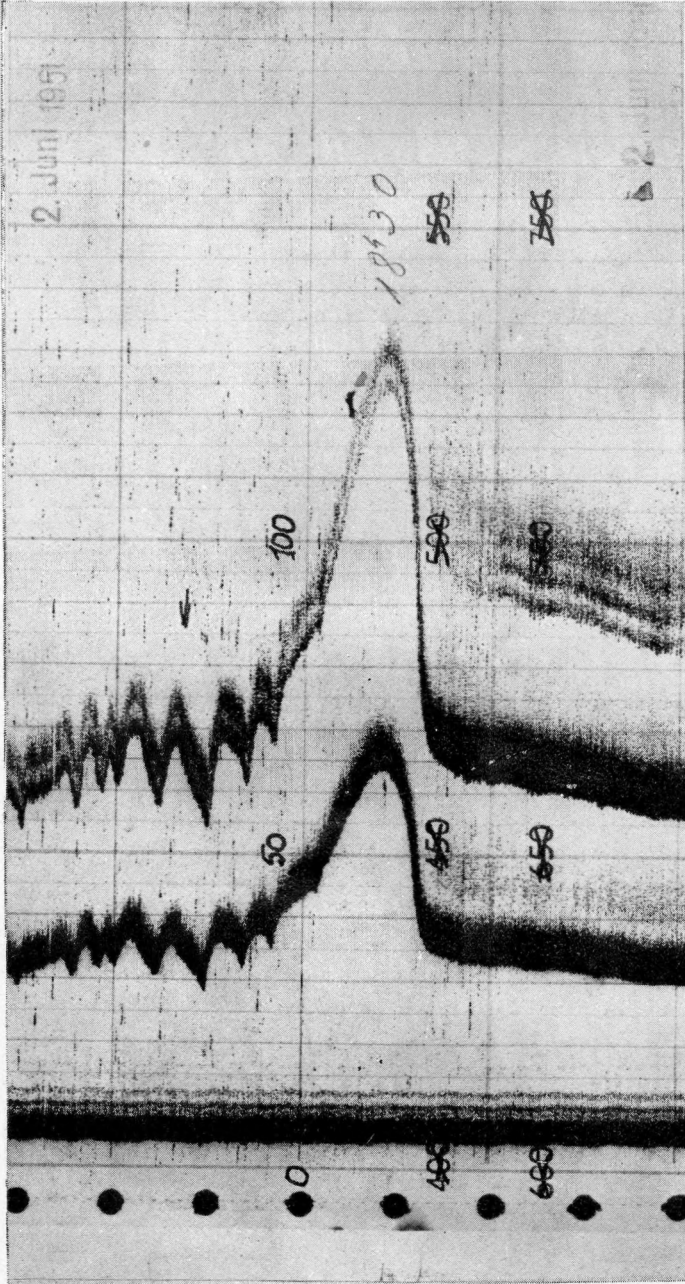


Fig. 1

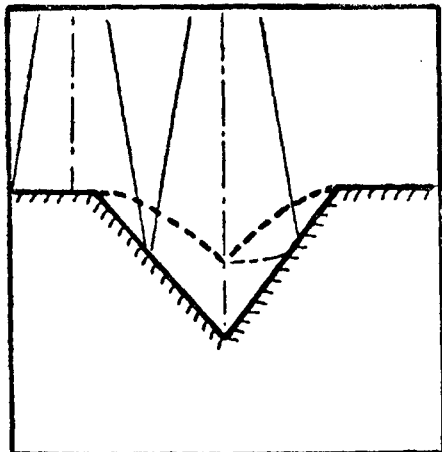


Fig. 2

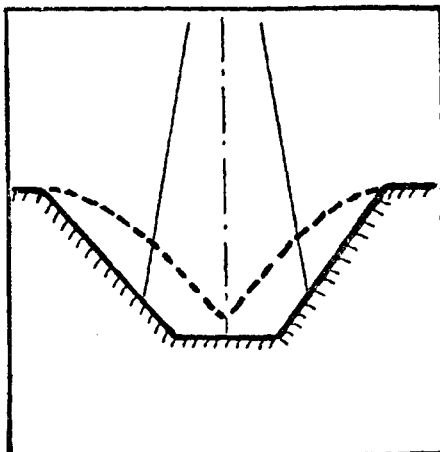


Fig. 3

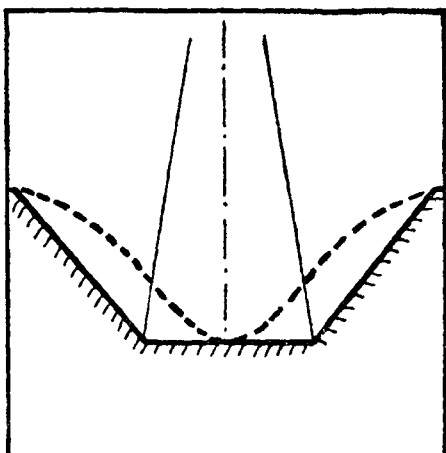


Fig. 4

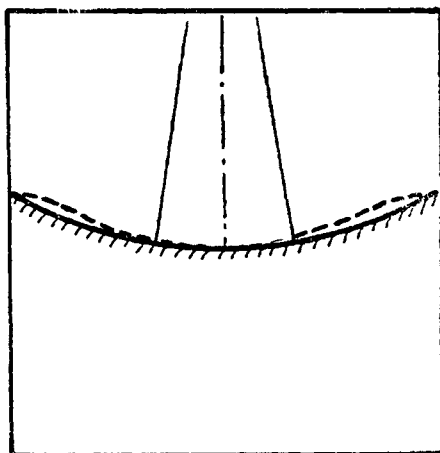


Fig. 5

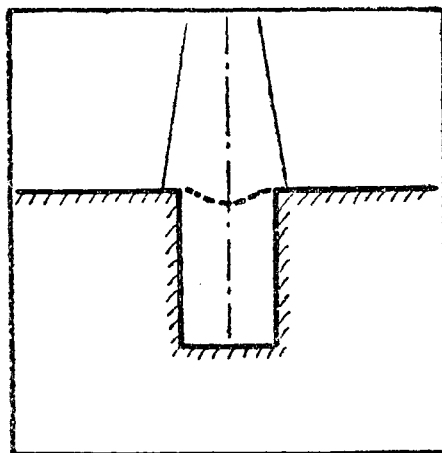


Fig. 6

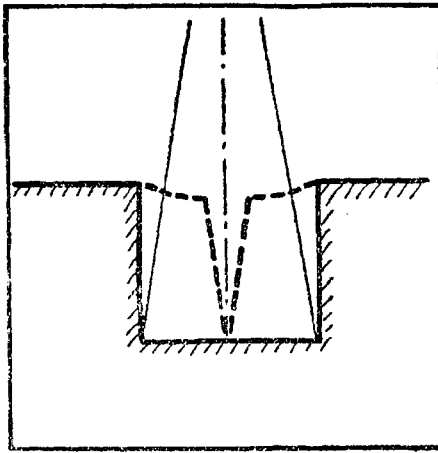


Fig. 7

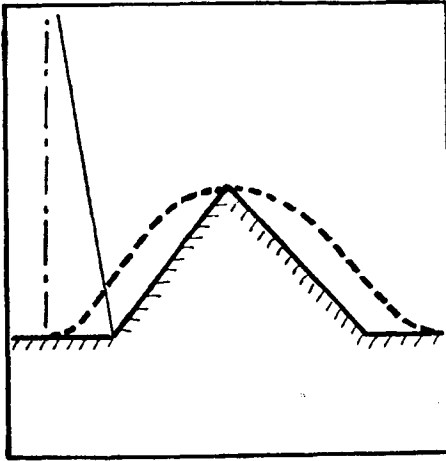


Fig. 8

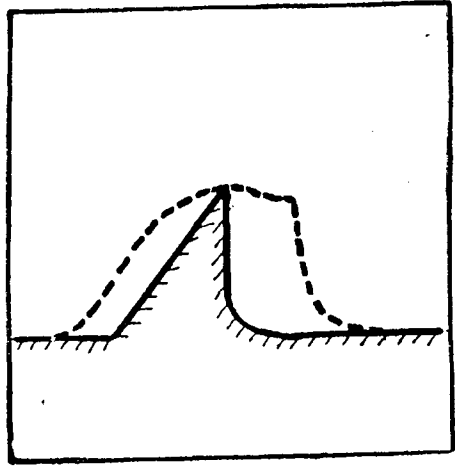


Fig. 9

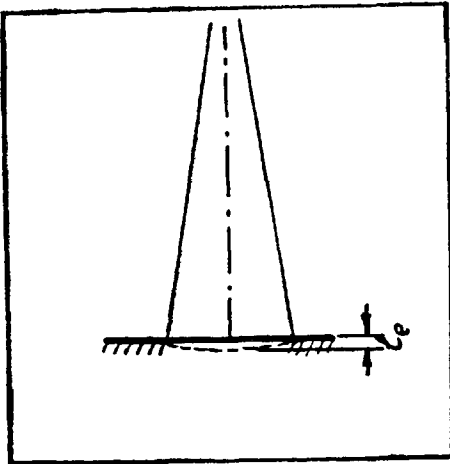


Fig. 10

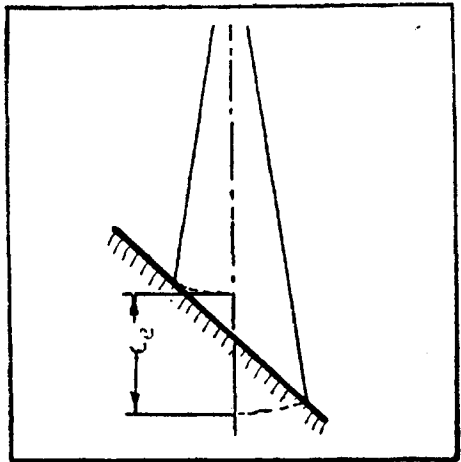


Fig. 11

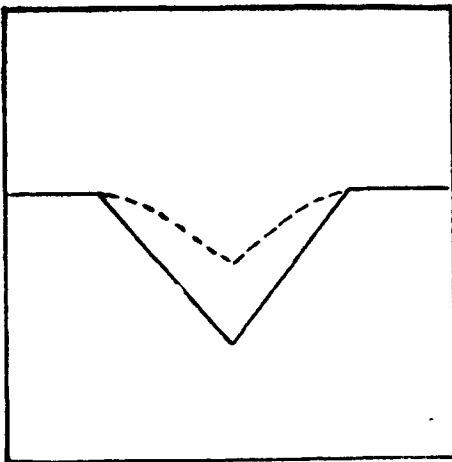


Fig. 12

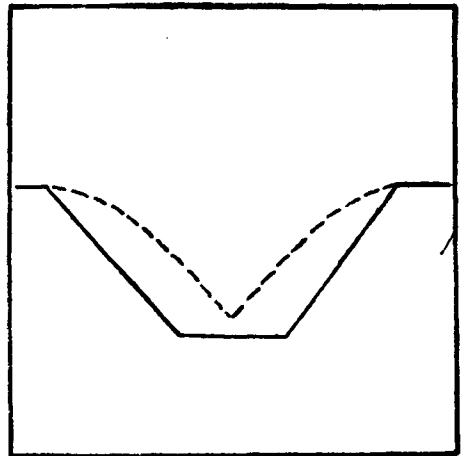


Fig. 13

time interval. They are united to form an extended total echo - the measurable echo length. In this connection, it is of decisive importance that this apparatus during operation is nearly free of a threshold of operation, i.e. that it also covers the boundary values of the effective cone of the apparatus.

When looking at echograms obtained in this manner (fig. 1), we are struck by the fact that the upper edge of the echo line exhibits the same levelling features as those we know from every spot light echo sounder used in navigation. There cannot possibly have been any change in the kind of representation, because the distance effect of the commercial equipment has remained exactly the same. The way natural forms of the sea bottom are levelled by scanning with caps is shown in Figs. 2 to 9; sketches have been made of typical forms of bottom configuration to which, I believe, nearly all possible irregularities of the sea bottom may be reduced.

What is furthermore striking during the exact study of the echograms is that the lower limit of the echo lengths cannot always be brought into line with the upper edge, and that visible differences exist both regarding the echo length and regarding the time of certain summits or depths. That leads us to investigate the timing of the representation of the bottom surface elements covered by the effective cone of the equipment. In this connection Figs. 10 and 11 are referred to, which show us the influence on the echo length of differences in the depth. It is not difficult to understand that great differences produce a greater echo length, while minor differences result in a smaller echo length.

Thus the recording method free of threshold of operation provides us with the possibility of making a fairly accurate estimate of the levelling tendency and in many cases even of computing it.

Figs. 12 to 19 are a repetition of the depth profiles shown in Figs. 2 to 9 with the lower edge of the echo length having been drawn into it, the effective cone being the same as before. The principles hitherto worked out for the evaluation of echograms may be summarized as follows :

a) If it is desired to ascertain the accuracy of representation by an echo sounder, the first requirement is to determine accurately the effective cone of the equipment.

b) If it is desired to check the bottom profiles in detail, it is necessary to study the lines of the upper edge and the lower edge of the echo lengths with a view to the position of outstanding places and the echo extensions, because these are a direct measure for differences in the depth within the effective cone.

c) Wherever a discontinuity occurs in the upper edge or wherever the lower edge is not parallel to the upper edge, differences exist between the profile drawn and the real profile.

d) Depressions will already become evident half the length of the effective cone earlier before reaching the depression, caused by the increasing of the echo length. In the case of elevations, the aspect of the upper and lower borders is reversed.

e) The lower boundary of the echo length is a better indication of the approximate shape of the profile.

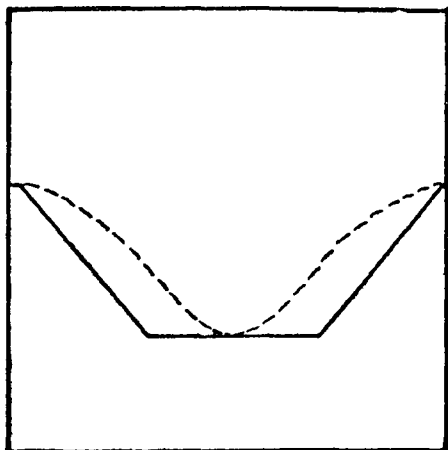


Fig. 14

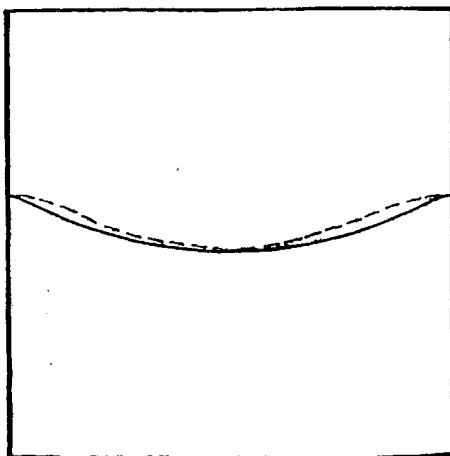


Fig. 15

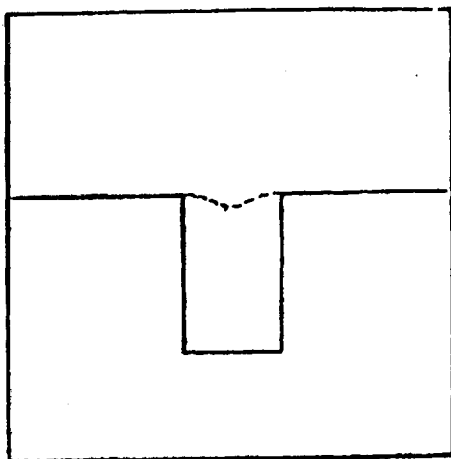


Fig. 16

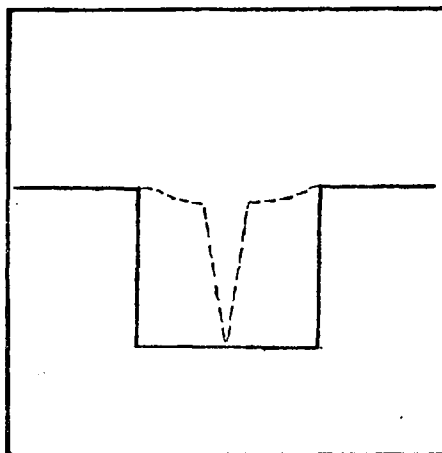


Fig. 17

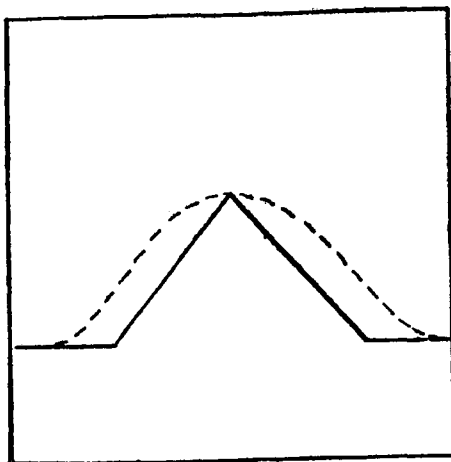


Fig. 18

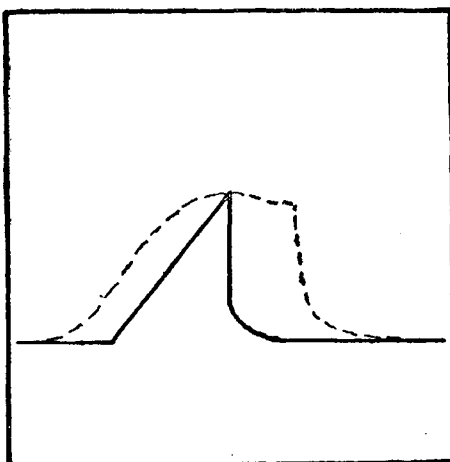


Fig. 19

The real configuration of the bottom will be computed by way of example, as below. First of all : Fig. 4. It is to be noted that it is not the intention here to go into further detail regarding the manner in which the absorption, the factor of reflexion, and the degree of amplification exercise an influence on the echo length. The intention of this paper is merely to state that certain conclusions can be drawn, and even computations can be made, from changes in the echo length regarding the actual configuration of the bottom. Let us assume therefore that the bottom be 100 m. deep, the degree of amplification be maintained constant, and that both at the bottom of the depression and at the top the material be sand. From the results of many measurements, we may assume that the aperture angle at the top of the characteristic line is 60° . The expected length of the echogram is :

$$100 + l_e = 100 / \cos 30^\circ = 100 / 0.866 = 115.8 \text{ m.}$$

$$l_e = 15.8 \text{ m.}$$

From this, we obtain the diameter of the effective cone :

$$d_{wb} = 2 \cdot 100 \cdot \tan 30^\circ = 200 \cdot 0.577 = 115.4 \text{ m.}$$

We assume the depression to be at a depth of 130 m., the width being $d_{wb} = 2 \cdot 130 \cdot 0.577 = 150 \text{ m.}$, which is said to be the corresponding diameter of the effective cone at a depth of 130 m. The angle of slope is 20° . If the sounding vessel approaches the depression from the left, the echogram shows a normal indication of the echo length, while the effective cone is above the level part of the sea bottom. This point is reached half a diameter of the effective cone before the depression begins. The following instant we note an increase in the echo length, as the outer edge of the effective cone is already sounding a lower-lying section of the slope. If the ship is in a perpendicular position over the beginning of the slope, the true depth of the bottom is still shown, but the echo length has been steadily increased by a certain amount as compared with the position just considered. In this connection, an auxiliary computation according to Figs. 20 and 21 is referred to. $l_e' = b$ is computed from the formula for oblique-angled triangles :

$$b = a \sin \beta / \sin \alpha ; a = d_{wb} / 2 = 57.7 \text{ m}$$

$$\beta = 20^\circ ; \alpha = (90^\circ - 30^\circ) - 20^\circ = 40^\circ$$

$$b = 57.7 \cdot 0.342 / 0.643 = 31.2 \text{ metres}$$

Accordingly, the echo length at this position is :

$$l_e + l_e' = 15.8 + 31.2 = 47.0 \text{ m.}$$

If the effective cone of the equipment unilaterally covers the difference in real depth, which amounts to $31.2 \cdot \cos 30^\circ = 31.2 \cdot 0.866 = 26.5 \text{ m.}$ the echo length increases from 15.8 m. to 47.0 m.

As another position of importance let us next consider that where the beginning of the depression is sounded by the outer edge of effective range. Then this point is the first point of reflexion and it is not the true depth of 100 m. that is recorded, but the apparent depth amounting to 115.8 m. Accordingly the depth mark of the bottom has slowly changed from 100 m. to 115.8 m. between these positions. The echo length is now twice as long as before, i.e. 62.4 m. As the depth indicated was but 115.8 m., a correction

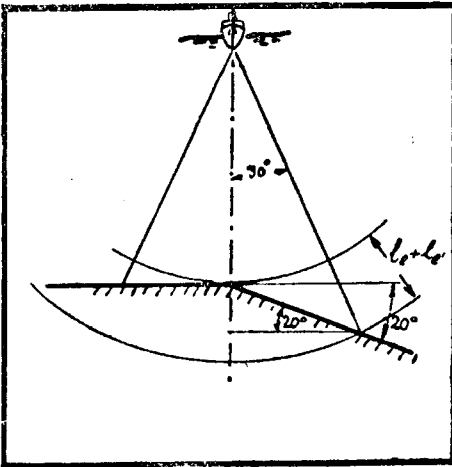


Fig. 20

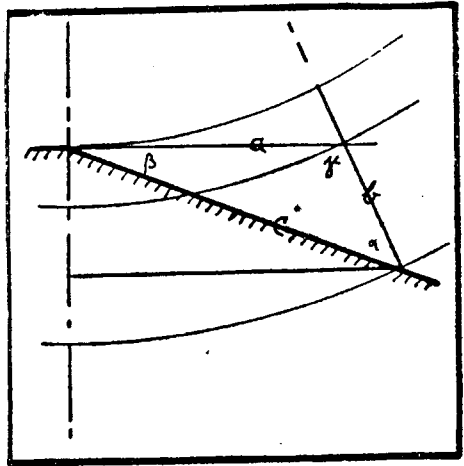


Fig. 21

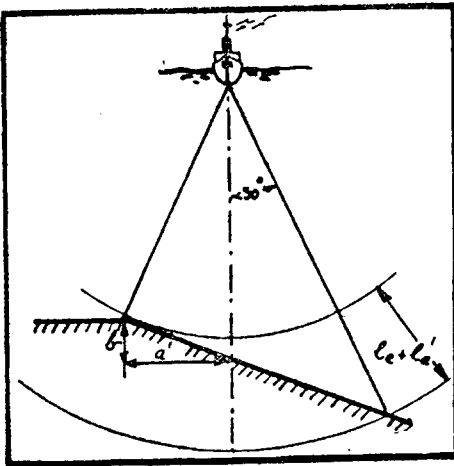


Fig. 22

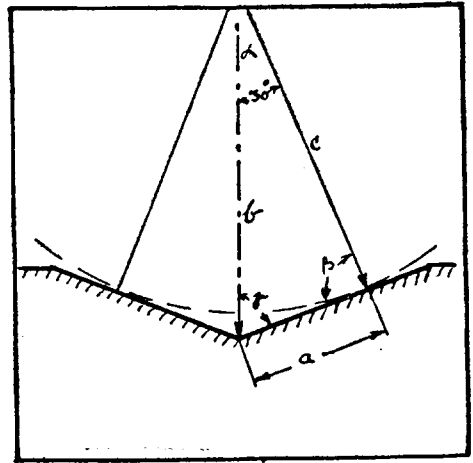


Fig. 23

+ 5,2 m is necessary in this position. The true depth in this position is (see Fig. 22) :

$$a'/115,8 = \sin \alpha ; \text{ hence } a' = 115,8 \cdot 0,5 = 57,9 \text{ m.}$$

$$\tan 20^\circ = b'/57,9 ; b' = 57,9 \cdot 0,364 = 21 \text{ m.}$$

hence the true depth is 121 m.

The extension of the echo length will continue until the angle of slope changes again, i.e. in our example until the bottom becomes level again at a depth of 130 m. The records will now gradually become shorter while the whole diameter of the effective cone covers the level ground (see figs. 4 and/or 14). In this position the echo length will have attained the following dimensions : beginning at 130 m., and ending at $130/\cos 30^\circ = 150$ m. As the ship proceeds, the process is repeated in reverse. The next illustration to be considered is Fig. 23. Let us check in the central position whether the true depth will become evident in the echogram. The start and process are exactly the same as in Fig. 14. The greatest echo length is attained while the effective cone of the equipment touches the slope. The very moment the extreme extent of the effective range again goes up the opposite slope, the echo length will become smaller till it has its relatively shortest extension in the central position shown in the drawing. As the ship proceeds over the trench, the echo length will become somewhat greater again until it reaches its greatest value when the range again covers the slope (Fig. 13). The echo length in the central position will be computed as follows :

The known terms are $b=130$ m.; $\alpha=30^\circ$; $\gamma=90^\circ - 20^\circ=70^\circ$

$\beta=(90^\circ - \alpha)+20^\circ=80^\circ$. The terms to be found are a and c :

$$a = b \cdot \sin \alpha / \sin \beta$$

$$= 130 \text{ m } 0,5 / 0,985$$

$$a = 66 \text{ m.}$$

$$c = a \cdot \sin (\alpha + \beta) / \sin \alpha$$

$$= 66 \text{ m } \sin 110^\circ / \sin 30^\circ$$

$$= 66 \text{ m. } 0,939 \cdot 0,5 ; c = 124 \text{ m.}$$

In the central position the echo length will become $130 - 124 \text{ m.} = 6 \text{ m.}$ (Fig. 12). In this case, the echo length will correspond to the value of correction, because the assumed depth of the base amounts to 130 m., and the depth value indicated at the upper edge of the bottom echo was determined to be 124 m. At the utmost, the echo length will be equal to the duration of pulses if the depression is adapted to the spherical cap and the effective cone has a rotatory symmetrical shape (vide Fig. 15).

Another example will answer the question of whether or not it will be possible to recognize and determine depressions of a width which is smaller than that corresponding to the diameter of the effective cone, i.e. the so-called cross-over effects. In this connection see Fig. 16. Assuming the diameter of the depression to be as great as that of the effective cone at this depth, the shortest depth remains defined by the boundaries of the effective cone, while parts penetrate to the bottom, viz. parts of the acoustic field adjacent to the perpendicular. They will give a true depth record. In this connection it makes little difference how great this value is, provided it is still within the range corresponding to the degree of amplification adjusted (see Fig. 16). A practical example is shown in Fig. 24. In the Norwegian Trench a deep of 440 m. was run over and only recognized afterwards.

It is reasonable to deduce from this that surveying operations in waters where deep and narrow trenches or holes are expected should be sounded with the maximum volume control the equipment has to offer.

Finally several examples are given of unreduced surveying echograms from the careful analysis of which essential conclusions may be drawn regarding the actual configuration of the bottom, even if the angle of slope is not known.

In Fig. 25 two deep trenches were sounded. The symmetrical shape of the echo length leads us to infer that the decline and rise of the slope are of a uniform shape. The markings of the individual pulses become gradually thinner. The echo lengths in the depression are almost exactly as long as in the bottom line, i.e. the bottom of the depression is level. Its width is somewhat greater than recorded in the bottom length, i.e. it corresponds to the lower horizontal limits of the echo lengths.

The diameter of the effective range is to be computed :

$$l_e \text{ read : } 43 \text{ m. ; echo depth read : } 234 \text{ m. ; hence } \cos \alpha = 234/277$$

$$\cos \alpha = 0.844 \text{ ; } \alpha = 32^\circ 20'$$

$$d_{wb} = 2.234 \cdot \tan 32^\circ 20' = 463.0.635 = 296 \text{ m.}$$

1 cm in the width of the echogram is really 2. 60. 5.25 = 630 m., if the ship proceeds at a speed of 10.5 miles per hour. The width of the lower boundary of the left depression is about 4 mm., i.e. about 252 m. for the real width of the base. The width of the depression further to the right of the base is 2 mm. in the echogram = 126 m. and can be recognized from outside as being of lesser width. At the upper boundary of the echo, the width of the echogram is estimated at only 100 m. The slope of the depression leads us to suppose that on the left slope there is a section which does not become sufficiently clear as shown by the upper edge of the echo alone. The rounded transition of the echo edge at the bottom of the depression shows that the base was really reached. In this connection attention is drawn to the strong oscillation of the echoes coming from the base which were indicated last. The width of the base is 2 mm. here, too, i.e. 126 m., but the echo depth being 155 m., the diameter of the effective cone is smaller ($d_{wb} = 2.155 \cdot 0.633 = 194 \text{ m.}$). Therefore the lower boundary of the echo lengths is not a straight but a curved line.

The next figure, N° 26, shows a very interesting echogram : the upper boundary of the echo from the bottom has a depression and a base which do not conform to the lower boundary. From what was said before, we may infer that the rise of the right-hand slope is certainly steeper than is indicated by the upper edge of the echo line, and that the base really lies where the echo dashes are abruptly broken. Its true depth is not represented accurately either ; it is probably 10 m. deeper than the record shows. At the position of the greatest echo length it is 62 m. In the case of the bottom being level and the echo depth 180 m. it should not amount to more than $180 \text{ m.} / \cos 38^\circ = 180 / 0.78 = 231 \text{ m.} - 180 \text{ m.} = 51 \text{ m.}$ We conclude from this that the rise produces an additional difference in the depth amounting to $\frac{62 - 51}{2} = 5.5 \text{ m.}$ in this position. Thus the real depth is not

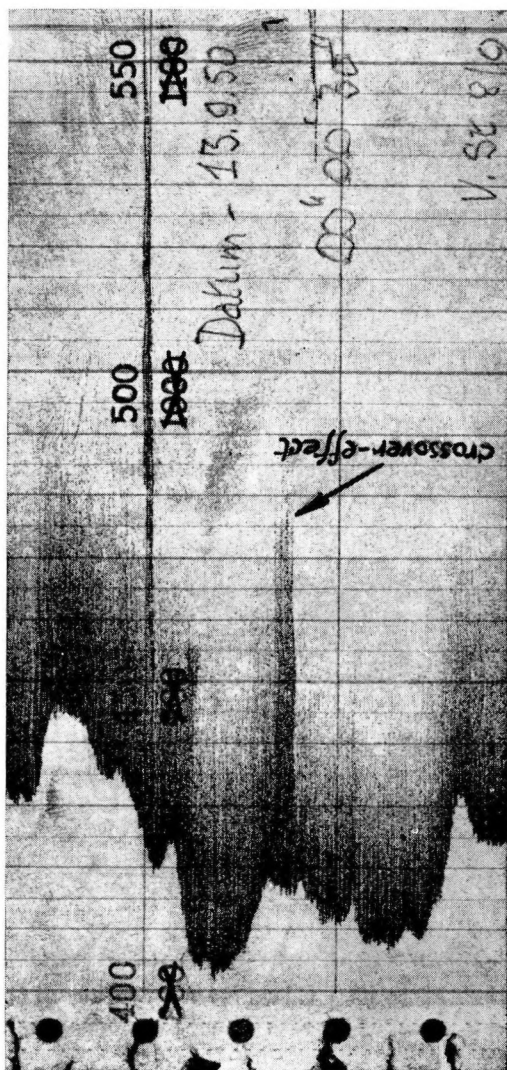


Fig. 24

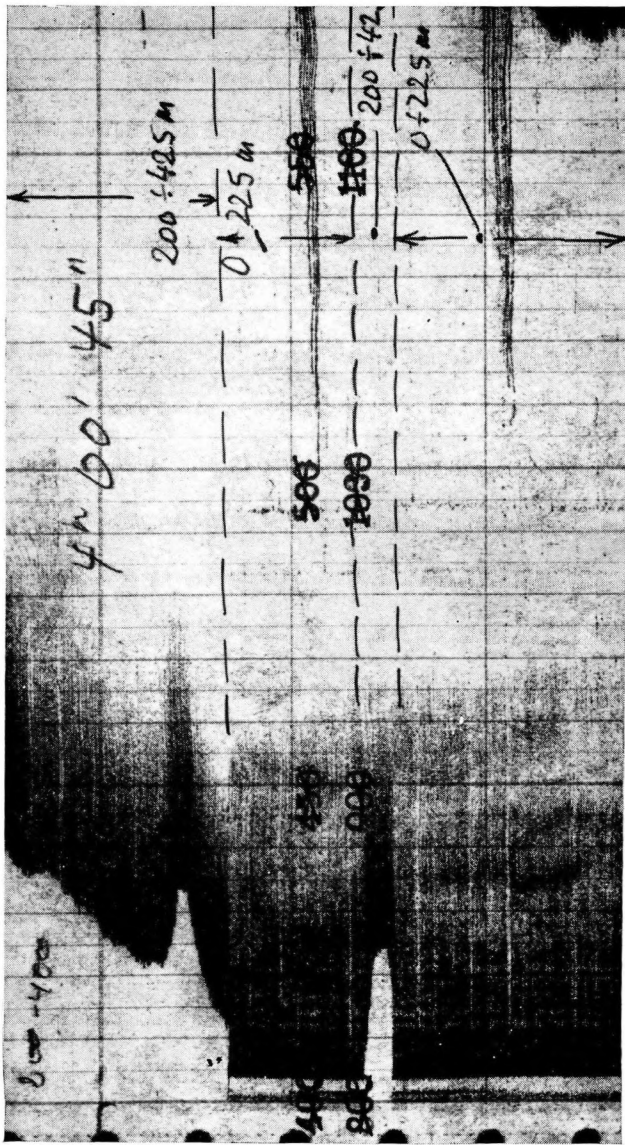


Fig. 25

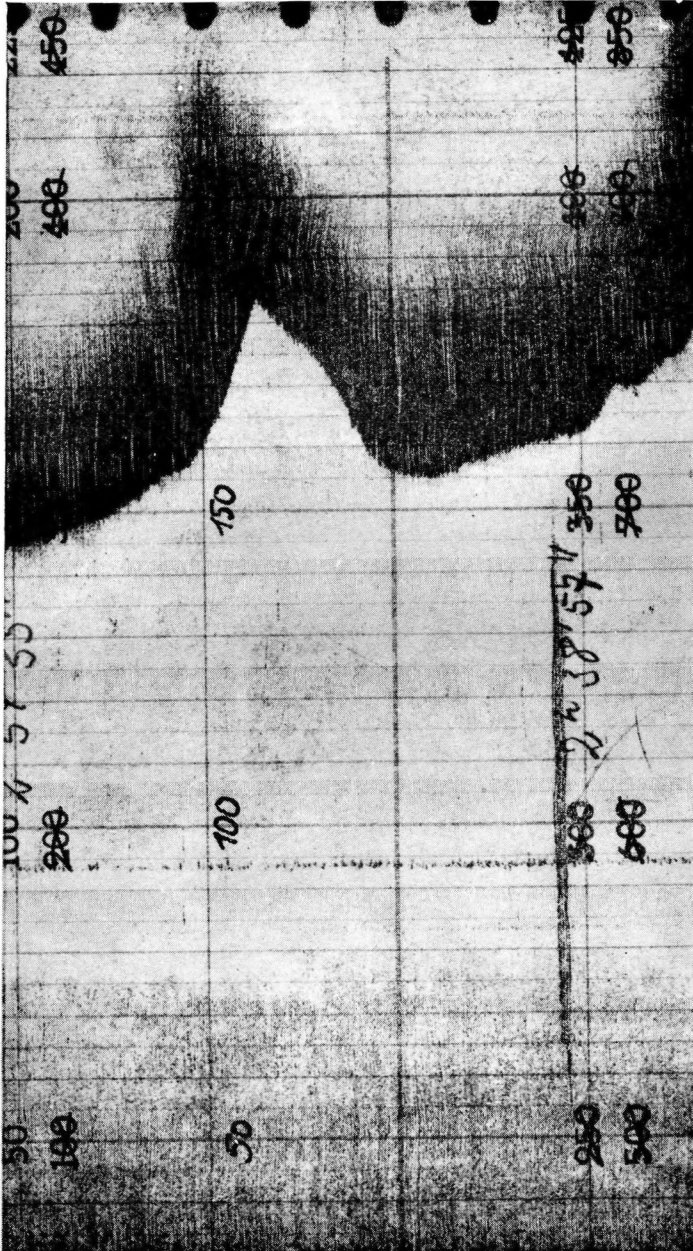


Fig. 26

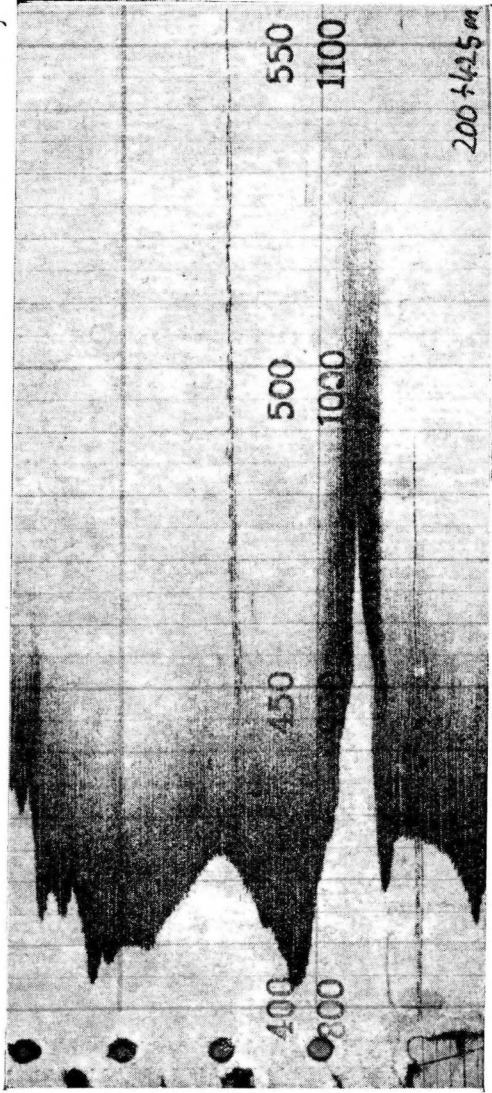


Fig. 27

165 m., but 170.5 m. Let us consider the echo length at the position where the upper edge of the echogram makes a sudden turn. It amounts to 33 m. there, thus being smaller than at comparable points on a level sea bottom. It should, however, amount to $l_e = 184/0,78 = 184 \text{ m.} = 236 - 184 = 52 \text{ m.}$ at an echo depth of 184 m. Accordingly, we have obviously reached the position where the rise is again covered by the effective cone so that we may only consider half the differences in the depth. If we want to draw the real traces of the depth according to all these considerations, in order to obtain a highly accurate picture of the profile, the computed values would have to be used. It is also expedient to pay attention to the following: in the lefthand section of the profile where the rise which is steep at the beginning commences to become less steep, we note a reduction as compared with the echo length of the level bottom. In the right-hand section where a great decline is shown, the echo lengths are considerably longer. A computation shows that the necessary correction to the base values is: 10.5 m.

In the following fig. 27, at about 0230, we see a very long echo. The real depth was not reached because the upper edge takes a sudden and abrupt turn. A computation shows that the base has to be corrected by about 40 m.

The remarks appearing in the present paper can also be applied to methods where the records are arc-shaped.

The indications derived from echograms obtained during the surveying of average depths in the North Sea and the Norwegian Trench are equally applicable to the surveying of minor depths where very irregular profiles prevail, such as in the mud flats off the German Coast of the North Sea and in parts of the South West North Sea. The interpretation of the echograms as regards the representation of true profiles for small depths is even easier, because a recorder having a smaller measuring range and accordingly a higher frequency of pulses may be used and because, therefore, better mean values may be formed. It is however advisable, when erratic profiles in small depths are sounded, that the duration of the pulses be then more marked. With the echo depth at 10 m. and the aperture angle of the effective cone at 60° , the echo length is about 1.6 m.; while the duration of the pulses in conventional echo sounders is about the same. An essential requirement for the construction of echographs to be used in waters of small depth is therefore the reduction of the duration of pulses.

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