MULTIPLE ECHOES IN ECHO SOUNDERS AND THE PROBABILITY OF DETECTION OF SMALL TARGETS (*)

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A study of multiple echoes was made in connection with hydrographic work in shallow waters such as port areas and power station reservoir lakes.

The analysis of reflection conditions leads to the conclusion that multiple echoes may be used for evaluating the reliability of soundings and the probability of detecting small objects such as stakes rising from the bottom, stones, debris and the like.

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Multiple echoes are often considered as a proof of good sensitivity of the echo sounding equipment. It is shown below that these echoes may also be used as a source of additional information as to the topography of the bottom, especially for evaluating the reliability of sounding.

There are two cases in which a reflection may occur. The first case is when the bottom is approximately flat and plane over an area greater than the cross section of the ultrasonic beam. The echo then is the result of *mirror reflection* and the range proportional to the second root of the radiated power.

The second case is when the bottom is uneven and rocky. The small features of such a bottom such as stones, stakes and similar objects can be considered as separate targets, the echo area of which is much smaller than the cross section of the beam and the range proportional to the fourth root of the radiated power.

A short analysis of the range equations and conditions necessary for the sounding and detection of small targets shows that multiple echoes may be used as a guide for evaluation of the depth at which a small target may be detected.

The range equation for an echo sounder can be deduced easily on the *mirror reflection* principle (fig. 1) as :

$$h = \sqrt{\frac{P_t G_t A \beta_b}{16 \pi P_{r \text{ min.}}}} \qquad (1)$$

(*) The subject article was originally intended for presentation to the General Assembly of IUGG, Toronto, September 1957.

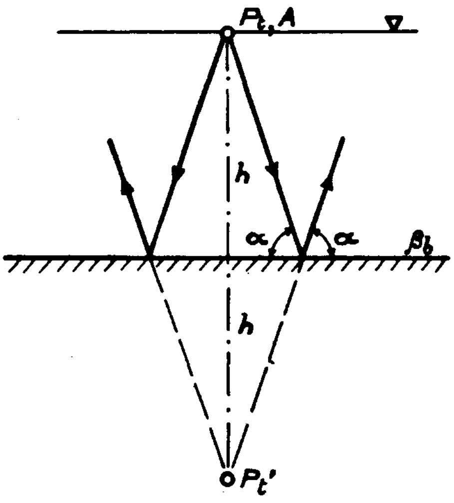

FIG. 1

where :

h = depth of sea;
P_t = peak of transmitted power;
G_t = gain of transmitting oscillator;
A = absorption area of receiving oscillator;
β_b = reflection coefficient of sea bottom;
$P_{r\ min.}$ = minimum discernible power received.

The sea bottom is in this case considered as a reflecting plane characterized by the coefficient β_b of dimensions greater than the ultrasonic beam cross section.

A small target, the area of which is small compared with the beam cross section, must be considered as a source of reradiated energy and the range equation consequently takes the form of the well-known " radar equation " :

$$\left(h = \sqrt[4]{\frac{P_t\, G_t\, A\sigma}{16\, \pi^2\, P_{r\,\text{min.}}}}\right) \tag{2}$$

in which σ denotes the echo area of the target and other notations are the same as in equation (1).

The comparison of these two equations shows that, with other parameters equal, the power needed for depth measuring only need be proportional to the second power of the depth, whereas for detection of small targets the power proportional to the fourth power of the depth is necessary.

Briefly :

for sounding : $P_t = const\ h^2$
for detection of a small target : $P_t = const\ h^4$ (3)

In other words, for detection of a small target a considerable reserve of power is needed, and then the echo sounder will record multiple echoes of the bottom profile as the result of multiple reflections between the bottom and the surface of the sea.

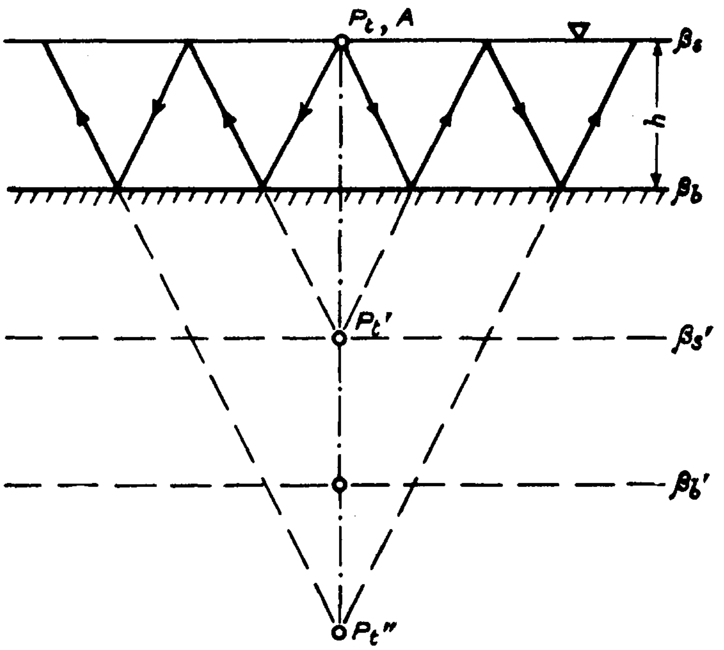

FIG. 2

For such multiple reflections the power equation may be deduced (fig. 2) as :

$$P_{tm} = \frac{16\,\pi\,P_{r\,\mathrm{min.}}}{G_t\,A} \cdot \frac{(nh)^2}{\beta_b^n\,\beta_s^{(n-1)}} \tag{4}$$

where :

β_b = reflection coefficient for sea bottom;
β_s = reflection coefficient for sea surface;
n = number of multiple echoes recorded.

Obviously $n \geqslant 1$ is an integer, but the notion of " strong " or " weak " echo recording may lead to a not necessarily integral intermediate value.

For a small target, as shown in equation (2) :

$$P_{st} = \frac{16\,\pi^2\,P_{r\,\mathrm{min.}}}{G_t\,A} \cdot \frac{h^4}{\sigma} \tag{5}$$

Hence the ratio of powers for these two cases is :

$$\frac{P_{st}}{P_{tm}} = \frac{\pi h^2}{\sigma n^2}\,\beta_b^n\,\beta_s^{(n-1)} \tag{6}$$

When sounding, P_{st} and P_{tm} are, of course, the same. Hence for $P_{st} = P_{tm}$:

$$h = n\sqrt{\frac{\sigma}{\pi\,\beta_b^n\,\beta_s^{(n-1)}}} \tag{7}$$

This relation shows at which depth a small target of a given echo area may be detected, if the echo sounder records n multiple echoes reflected from the bottom having a reflection coefficient β_b with the sea state characterized by the reflection coefficient β_s.

On a calm sea, the surface reflection is almost total, $\beta_s = 1$.

The bottom reflection coefficient may be known from the chart of the area investigated or very often may be approximately evaluated from the recorded bottom profile. Here the multiple echoes may also give interesting information.

The relation (6) is shown graphically on fig. 3, for different kinds of bottom, with the echo area of the target taken as $\sigma = \pi$ and for $\beta_s = 1$. The value $\sigma = \pi$ seems reasonable for shoals of fish, small wrecks and similar objects.

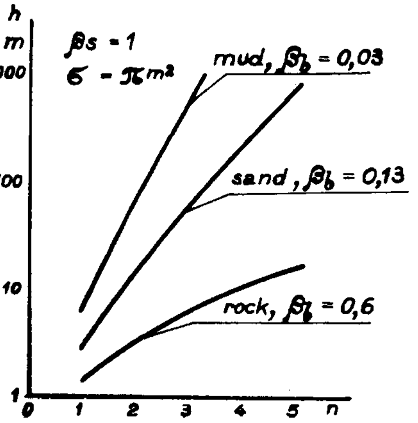

FIG. 3

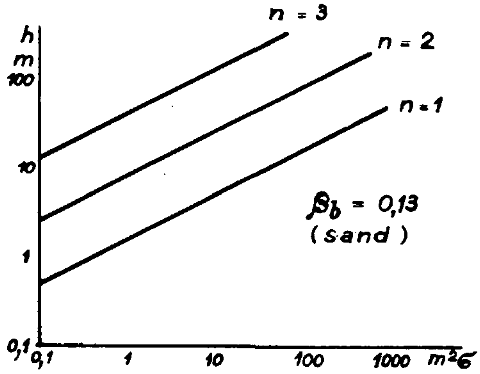

FIG. 4

The graph shows how the probability can be estimated of detecting a target of echo area $\sigma = 3.14$ m^2.

When sounding above a hard, rocky (but flat) bottom the number of multiple echoes should be relatively large. For example the fourth echo shows the probability of detection of the target at a depth of no more than about 10 m, whereas above a sandy bottom the same fourth echo has a good chance of detecting the same target at a depth of about 200 m.

If the bottom is muddy even the second echo is sufficient for detection at a depth of about 70 m.

On the high seas, i.e. for $\beta_s < 1$, the number of necessary secondary echoes is smaller, but it must be borne in mind that the general conditions of sounding deteriorate when the ship is rolling.

In fig. 4 the depth as a function of σ is drawn for a specific bottom with the number of multiple echoes as a parameter. Such graphs may be drawn for any kind of bottom encountered in the investigated area. They may be very useful for estimating to what extent the echo sounder may be relied upon for detection of targets the size of which may offer a navigational hazard. It is evident that it is worthwhile to secure as great a number of multiple echoes as possible, because the thoroughly investigated depth is directly proportional to the number of multiple echoes, whereas the target size is of somewhat less importance, since σ is in the square root.

The sounding range equation (1) was based on the assumption that the sea bottom is flat and horizontal. Obviously this is not always the case, especially when the bottom is hard. When the bottom is inclined as shown in fig. 5 the conditions for sounding are worse and an echo can be obtained if the inclination angle α is smaller than half a beamwidth referred to 3 db. The trace recorded corresponds to the shortest distance h'.

A sounding error results :

$$\Delta h = h - h' = h\ (1 - \cos \alpha). \tag{8}$$

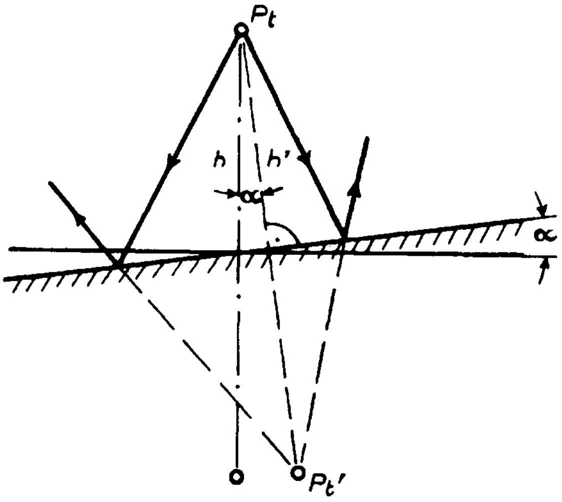

FIG. 5

The multiple echo originates from the equivalent distance of $n \cdot 2h$ and from the equivalent bottom inclined at an angle $n\alpha$. The geometry of this case is shown in fig. 6. The multiple echo cannot be received unless the inclination of the bottom is n times smaller than the half beamwidth of the receiving oscillator. It is evident that the multiple echoes, especially those of the higher order, may be lost.

That is why multiple echoes over an uneven, rocky bottom are usually very weak and sometimes only the peaks and pits of the rocks are marked.

A similar situation occurs when the ship is rolling — the depth may still be recorded with a strong, continuous trace but the multiple echoes are interrupted.

The inclination effect must be taken into account when multiple echoes are used as a guide to estimate the chance of detecting a small target.

The multiple traces are often recorded not with one trace, but with sets of two, three of more traces, their number corresponding to the number of multiple echoes.

The reason is simple : the pulse is reflected not only from the surface of the sea, but also from the bottom of the ship. As a result two traces are marked for the second echo, the distance between them being equal to the draft of the ship. With each multiple reflection one more trace is thus added.

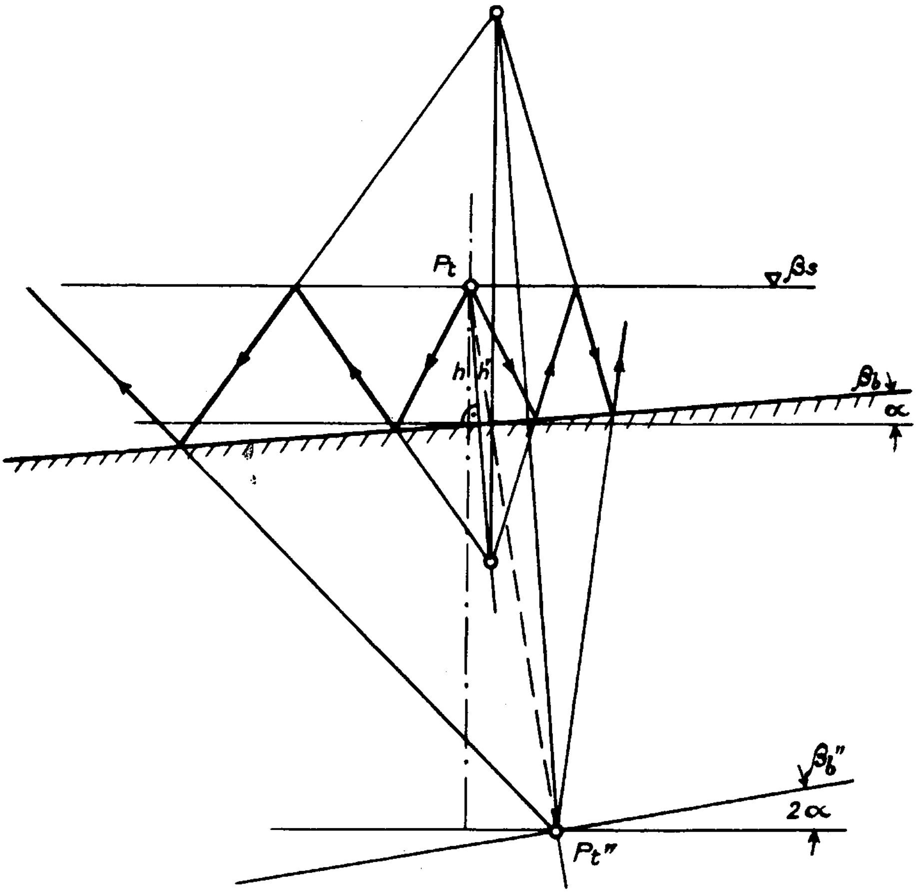

FIG. 6

The relative intensity of the traces belonging to the echo of the same order very often changes as the ship is moving.

Sometimes the upper trace and sometimes the lower one is stronger — one may be clear-cut and strong and the other one wide and occasionally blurred.

The experimental data that we now possess are not extensive enough for drawing a definite conclusion from this fact, but it seems that there is some relation between the relative intensity of the traces and the bottom structure.

From range equations and experiments the conclusion may be drawn that multiple echoes are able to give valuable information, especially in flat, shallow depths.

Such conditions are often met in hydrography when sounding, as in water courses, harbour areas, lakes and so on. These are the cases where detection of small targets is very important.

Of course, the multiple-echoes method cannot be considered as a foolproof method for finding small underwater obstacles, but for an experienced operator it may give quite a lot of valuable information.