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ACOUSTIC ENERGY LOSSES ON REFLECTION FROM SELECTED FLOORS OF THE SOUTH BALTIC

Contents:

1. INTRODUCTION

In the propagation of sound in a shallow sea, such as the Baltic, a paramount role is played by the acoustic properties of the sea floor. A couple of parameters, such as pressure reflectivity, reflection losses, scattering factor, and scattering power are usually employed in the quantitative description of the reflective and diffusive properties of the sea floor. The magnitude of reflectivities for normal incidence of the acoustic wave on the sea floor determines the maximum losses of energy to be anticipated in the reflection of sound.

The purpose of this study was to find the relationship between the acoustic reflectivity on the sea bed and the frequency of incident acoustic waves, angle of incidence, and type of sediments. The measurements were conducted at frequencies from 2 to 10 kHz (at tertiary intervals, i.e. for frequencies of 2, 2.5, 3.15, 4, 5, 6.3, 8, and 10 kHz) for three types of sea bed: fine sand of 0.145-mm median, very fine sand of 0.120-mm median, and soil consisting mainly of macrofauna (shells of molluscs and snails).

2. THEORETICAL ASSUMPTIONS AND METHOD OF MEASUREMENTS

The experiments were conducted by the method of standing waves, which yields the most accurate results [9, 10]. The method consists in the measurement of a resultant acoustic pressure at the minima and maxima of a standing wave that results from the interference of two acoustic signals, that directly from a transmitter and the bed-reflected one (Fig. 1).

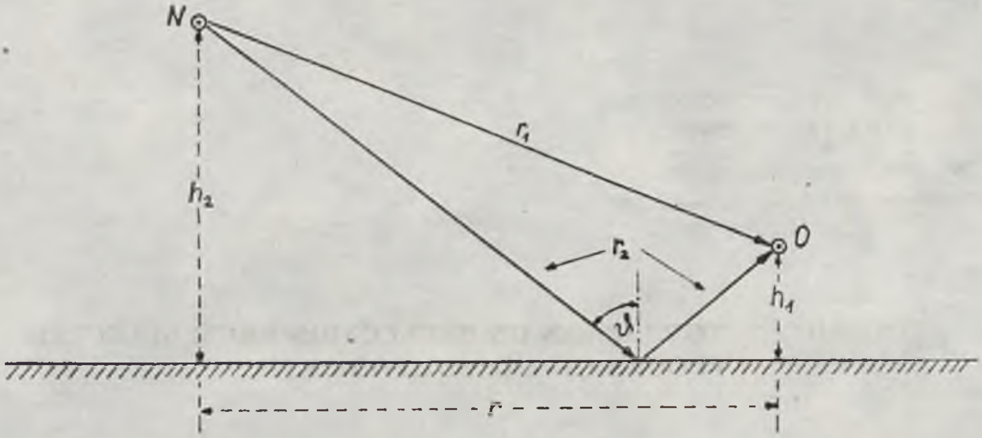


Fig. 1. Configuration of transmitter (N) and receiver (0) for the incidence angle of an acoustic wave on the bottom $\vartheta \neq 0°$

r_1 — distance travelled by incident acoustic signal
r_2 — distance travelled by reflected acoustic signal
h_1 — distance from bed to receiver
h_2 — distance from bed to transmitter
r — distance between receiver and transmitter (in horizontal plane)

Ryc. 1. Usytuowanie nadajnika (N) i odbiornika (0), gdy kąt padania fali akustycznej na dno $\vartheta \neq 0°$

r_1 — droga przebyta przez sygnał akustyczny bezpośredni
r_2 — droga przebyta przez sygnał aksutyczny odbity od dna
h_1 — odległość od dna do odbiornika
h_2 — odległość od dna do nadajnika
r — odległość pomiędzy nadajnikiem i odbiornikiem (w płaszczyźnie poziomej)

For a point source of sound, the pressure of the acoustic wave travelling directly from a transmitter to a receiver has the form:

$$p_i = p_o/r_1 \exp(-ikr_1) \quad (1)$$

in which:

p_o — acoustic pressure at a unit distance from the transmitter,
r_1 — distance the acoustic signal travels directly from transmitter to receiver (Fig. 1),
$k = 2\pi/\lambda$ — acoustic wave number,

while the pressure of the bed-reflected wave is given by

$$p_s = p_o/r_2 \cdot \exp(-ikr_2) \quad (2)$$

in which:

r_2 — distance travelled by the acoustic signal from transmitter to receiver, after reflection from the sea bed.

The pressure reflectivity is given by the following formula:

$$V = V_o \cdot \exp(i\varphi) \quad (3)$$

in which:

V_o — absolute value of reflectivity,

φ — phase of reflectivity.

The resultant acoustic pressure of the point of reception equals

$$p = p_s + p_i \tag{4}$$

After taking into account Eqs. (1, 2) and (3) one obtains the following relationship for absolute pressure:

$$|p| = \left\{ \frac{p_o^2}{r_1^2} + \frac{p_o^2\, V_o^2}{r_2^2} + \frac{2p_o^2 V_o}{r_1\, r_2} \cos\left[k\,(r_2 - r_1) - \varphi\right] \right\} \tag{4}$$

This pressure will be maximum if $\cos[k\,(r_2 - r_1) - \varphi] = +1$ and minimum if $\cos[k\,(r_2 - r_1) - \varphi] = -1$. Upon substituting consecutive cosine values of $+1$ and -1 in Eq. (4) and solving the resulting system of two equations (with respect to V_o) one obtains

$$V_o = \frac{\dfrac{p_{max}}{r_1 min} - \dfrac{p_{min}}{r_1 max}}{\dfrac{p_{max}}{r_2 min} + \dfrac{p_{min}}{r_2 max}} \tag{5}$$

in which: $r_{1,2}\,max$ and $r_{1,2}\,min$ = distances r_1 and r_2, determined above, and counted to the receiver in the phases of standing-wave maximum and minimum, respectively.

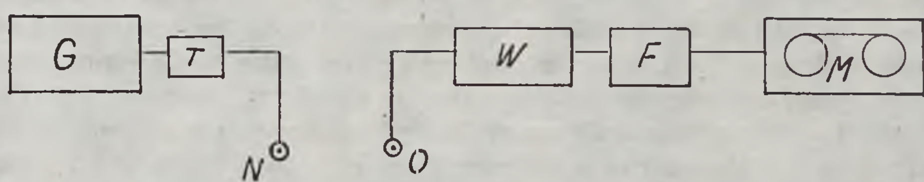


Fig. 2. Schematic diagram of transmitting, receiving, and recording configuration

G — power generator, type PO-21 (KABID-ZO PAN)
T — transformer
N — transmitter: cylindrical piezoceramic transducer
O — receiver: 8101 Brüel-Kjaer hydrophone
W, F — amplifier and set of filters: 2120 Brüel-Kjaer analyzer
M — magnetic voltage recorder, Brüel-Kjaer 7003

Ryc. 2. Schemat układu nadawczo-odbiorczo-rejestrującego

G — generator mocy typ PO-21 (KABID-ZO PAN)
T — transformator
N — nadajnik: cylindryczny przetwornik piezoceramiczny
O — odbiornik: hydrofon 8101 (Brüel-Kjaer)
W, F — wzmacniacz z zestawem filtrów: analizator 2120 (Brüel-Kjaer)
M — rejestrator magnetyczny napięcia 7003 (Brüel-Kjaer)

Where the distance travelled by an acoustic signal from the transmitter to receiver, is much greater than the acoustic wave-length (and consequently — than the distance between adjacent standing-wave minimum and maximum) one can assume $r_{1\,min} \simeq r_{1\,max}$ and $r_{2\,min} \simeq r_{2\,max}$.

Accordingly, the ultimate formula for the absolute value of reflectivity reads:

$$V_o = \frac{r_2}{r_1} \frac{p_{max} - p_{min}}{p_{max} + p_{min}} \tag{6}$$

Hence, this absolute value may be found for known r_1 and r_2 (from the geometrical configuration of experimental environment) and for acoustic pressure measured at the nodes and antinodes of standing waves.

3. EXPERIMENTAL TECHNIQUES

The block diagram of the measuring system is shown in Fig. 2. The transmitting components consisted of a PO 21-type power generator, and a piezoceramic transducer with a conical shield with 45° angle of aperture. The shield was necessary to eliminate interference due to scattering of sound off the undulated sea surface. The reception components included a hydrophone (type 8100), amplifier with a set of filters (type 2120), and measuring tape recorder (type 7003), all instruments manufactured by Brüel Kjaer. A special structure (Fig. 3) to move the hydrophone along the vertical axis was designed to determine the maxima and minima of standing waves. The positions of the hydrophone were found from indications of a counter, which recorded the number of revolutions of a threaded rod, along which the motion occurred. The accuracy of receiver setting at the extremum of the standing wave was 3.5-mm (pitch of rod thread), which was sufficient for the wavelength encountered (75... 15 cm). The supporting structure of the hydrophone was set firmly on the bed, while the transmitter was lowered on a jib to a depth of 1.5... 2 m below the water surface. After the automatic switching-on of the hydrophone (this being controlled by an electric motor), the deflection of a pointer, corresponding to changes in acoustic pressure, was observed on the measuring amplifier scale. The hydrophone was stopped for maximum and minimum pointer deflections, and a 100-second magnetic recording taken. For each frequency the measurements were repeated for several consecutive minima and maxima. The value obtained from the 100-second averaging was accepted as the pressure for standing-wave minimum and/or maximum. This procedure permitted random interference and fluctuations of the acoustic signal to be avoided at the point of reception. The averaging was accomplished automatically with an integral system built in a Brüel Kjaer 2120 analyzer.

The hydroacoustic measurements were accompanied by sampling of bed surface sediments, the latter having been subject to grain size analysis. The analysis was performed on a set of 13 sieves bounded by 5 and 0.063 meshes.

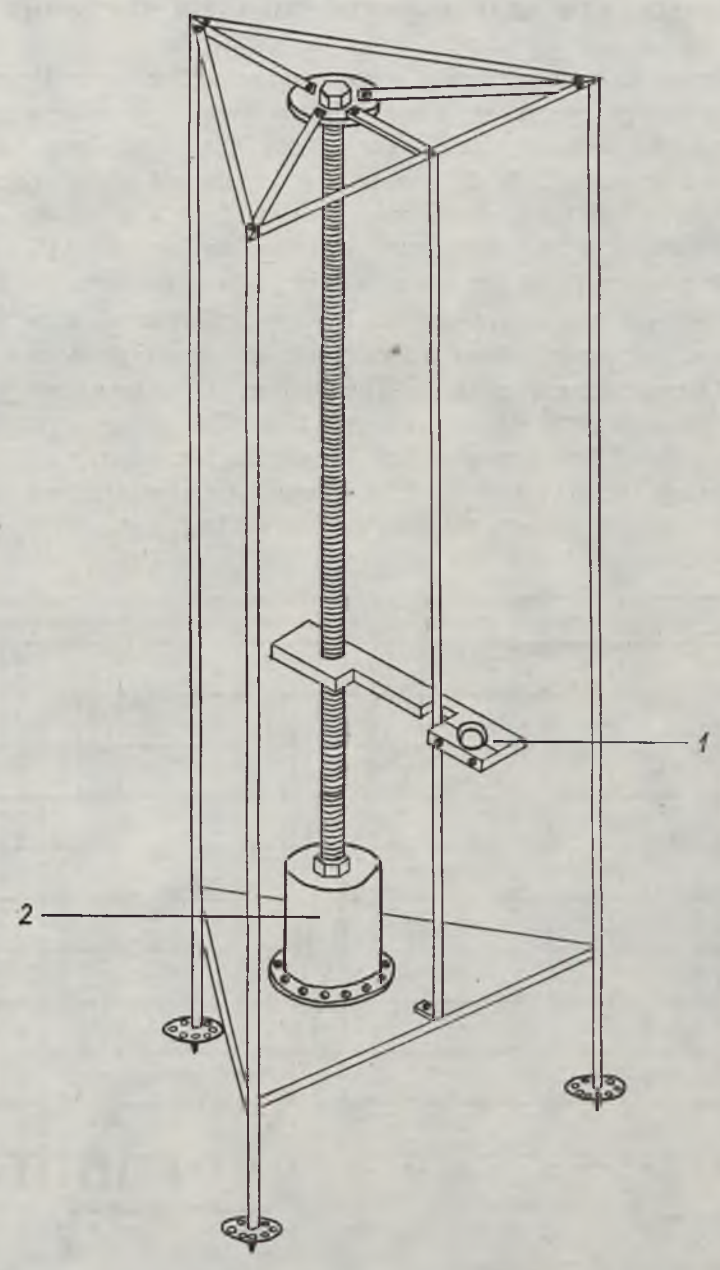


Fig. 3. Schematic diagram of hydrophone structure

1 — hydrophone clamp
2 — electric motor in waterproof casing

Ryc. 3. Schemat konstrukcji nośnej hydrofonu

1 — uchwyt do hydrofonu
2 — silnik elektryczny w obudowie wodoszczelnej

4. RESULTS OF MEASUREMENTS AND THEIR DISCUSSION

Hydroacoustic measurements were conducted for three types of sea bed. The first type consisted of macrofauna and very small admixtures of fine, as well as medium sand. The molluscs *Mytilus edulis* and *Cardium Lamarcki* and tiny snails 2... 30 mm in size dominated in the species composition. The second type of soil was fine sand with a maximum share of grains of about 0.16... 0.10 mm, the median being 0.145 mm. The Trask sorting factor [7, 8] for these sediments was fairly high: 1.75. The third type of bed was characterized by the occurrence of two distinct layers. The upper layer, about 0.2 m thick, of very high water content, consisted of fine and medium sands. The median of this layer was 0.195 mm while the Trask sorting factor reached 1.70. The other layer included highly consolidated fine and very fine sands. Their median was 0.120 mm, and the sorting factor was 1.37. The integral curves obtained from the grain size analysis of the soil samples are shown in Fig. 4.

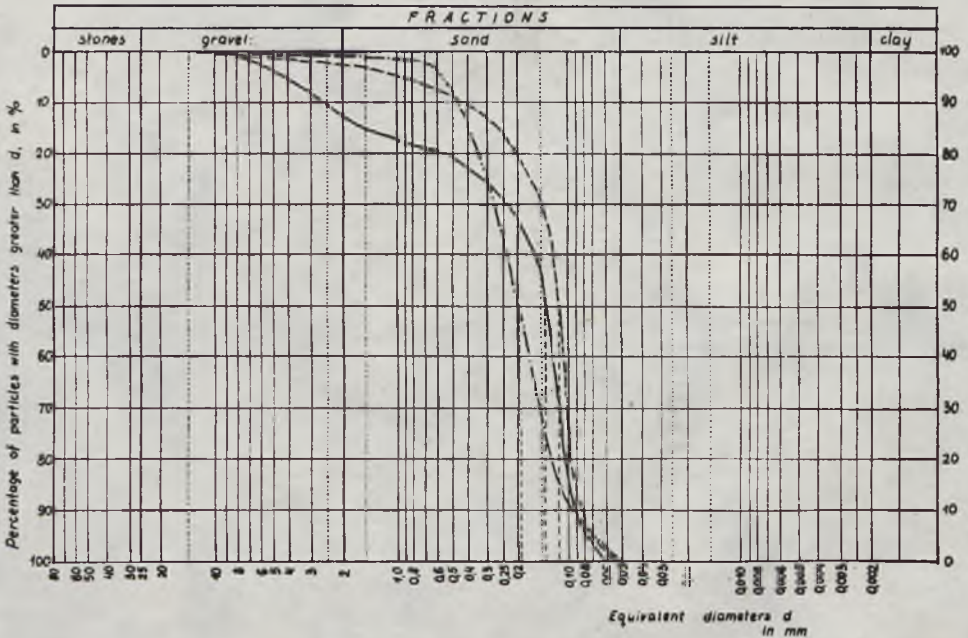


Fig. 4. Integral curves of grain size

——— measuring point 2: fine sand
—·—·—·— measuring point 3: layer I (Upper), fine sand
— — — — measuring point 3: layer II (lower), fine and very fine sand

Ryc. 4. Wykresy uziarnienia gruntu (krzywe kumulacyjne)

——— dla punktu pomiarowego 2: piasek drobnoziarnisty
—·—·—·— dla punktu pomiarowego nr 3: warstwa I (górna), piasek drobnoziarnisty
— — — — dla punktu pomiarowego nr 3: warstwa II (dolna), piasek drobno- i bardzo drobnoziarnisty

The absolute values of the reflectivities for normal incidence of acoustic waves at the sea bed, averaged over frequencies of 2 to 10 kHz, for the three types of soil, were as follows:

macrofauna		$V_o = 0.59$
fine sand	(Md = 0.145 mm)	$V_o = 0.55$
very fine sand	(Md = 0.120 mm)	$V_o = 0.61$.

The results obtained agree with the findings for other water bodies under similar conditions and experimental technology [2, 5, 10]. For instance, our data fall into the interval of variability of reflectivities given by Libermann [5], who obtained 0.50... 0.60 for a stony bottom, 0.40... 0.86 for sand, and 0.40... 0.60 for soil consisting of sand and clay. The diameters of the particles of the stony floor studied by Libermann coincide well with the size of our macrofauna, so that the reflectivities in both cases were very similar. Moreover, it should be concluded that this coincidence was fortuitous, as the acoustic properties of the sea floor are determined not only by the size of bottom sediments. Our figures are lower than the data given by Grubnik [2] for the Caspian Sea, with mean absolute values of reflectivities of 0.76 and 0.68 for sand and silty sand, respectively. Mackenzie [6] also detected reflection losses of 6... 8 dB for very fine sand, which correspond to an absolute magnitude of reflectivity of about 0.5... 0.4.

The dispersion of data indicated by the above results obtained by various authors can be due to bottom irregularities, diversified internal structure, and rather inaccurate nomenclature of bed sediments (since different criteria of the classification of sediments are in use, it is necessary to specify the distribution of respective sediment fractions, together with the type of soil, e.g. sand or clay).

The absolute values of reflectivity found in this study are shown in Fig. 5 as a function of the frequency of the acoustic signal. No clear dependance of the reflectivity on the length of the acoustic wave was found in the studied interval of frequencies from 2 to 10 kHz, at tertiary spacing. Similar results were obtained by Grubnik [2], see Fig. 6. However, after the results of our experiments were obtained, a study by Goncharenko et al. [4] appeared, in which the above relationship was exposed for two-layer bottom. Their findings conform reasonably with Brekhovskikh's computations for a multilayer bed. The function of absolute reflectivity versus frequency is illustrated in Fig. 7. The function $V_o(f)$ is oscillatory, its period changing with the incidence angle of acoustic waves at the sea floor (with the exception of the case $C_2 \ll C_o$, in which C_2 and C_o are speeds of sound in the upper floor layer and in water, respectively). The frequency relationships obtained for various angles of incidence can be used in computations of the characteristics of respective bottom layers.

The lack of a frequency function for the absolute reflectivity, in our

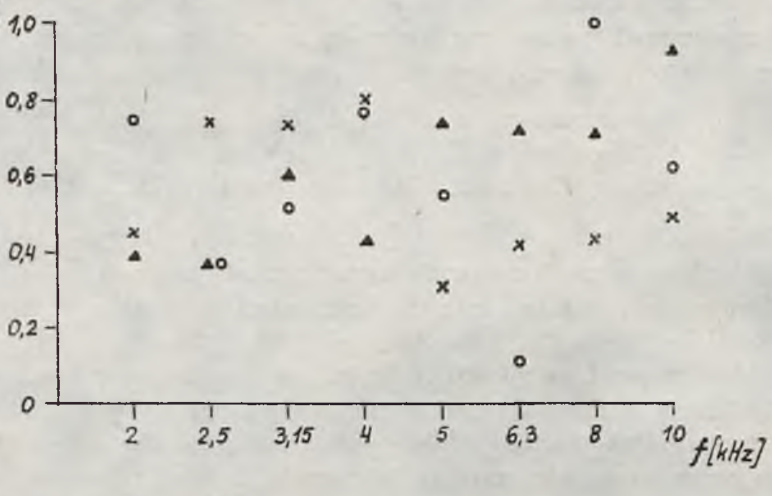


Fig. 5. Absolute value of reflecitivity, V_o, versus frequency of acoustic wave f($\vartheta = 0°$)

o data for macrofauna
x data for fine sand
Δ data for very fine sand

Ryc. 5. Zależność modułu współczynnika odbicia (V_o) od częstotliwości fali akustycznej f ($\vartheta = 0°$)

o dane dla makrofauny
x dane dla piasku drobnoziarnistego
Δ dane dla piasku bardzo drobnoziarnistego

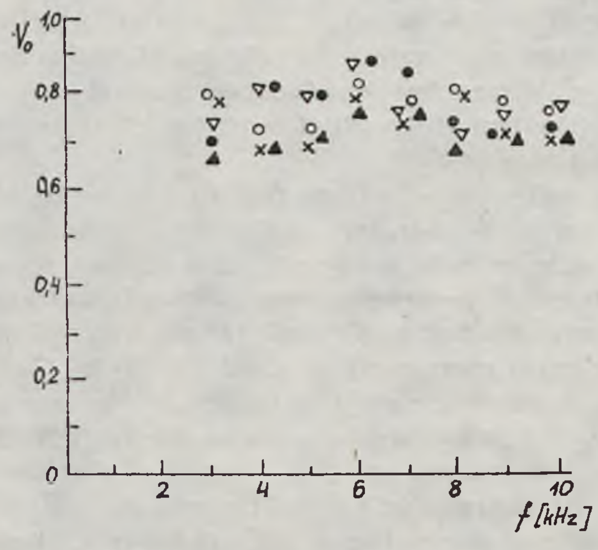


Fig. 6. Experimental absolute values of sea-floor reflectivity, V_o, versus frequency. Different notations correspond to various measuring points. According to Grubnik [2]

Ryc. 6. Eksperymentalne wartości modułu współczynnika odbicia V_o od piaszczystego dna w funkcji częstości. Poszczególne oznaczenia odpowiadają różnym punktom pomiarowym. Wg pracy N.A. Grubnik [2]

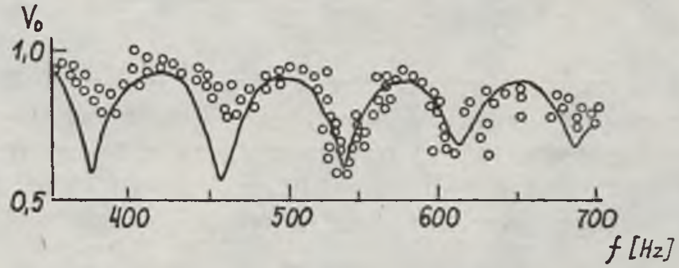


Fig. 7. Absolute value of reflectivity versus frequency for a two-layer model of the sea floor (the case $C_2 \ll C_0$, in which C_2, C_0 — speeds of sound in the upper layer and in water, respectively). According to Goncharenko, Zakharov, Ivanov, Kirshov [3]

O experimental data

—— theoretical curve

Ryc. 7. Zależność częstotliwościowa modułu współczynnika odbicia dla dwuwarstwowego modelu dna (przypadek gdy $C_2 \ll C_0$; gdzie C_2, C_0 — prędkości dźwięku odpowiednio w powierzchniowej warstwie dna i w wodzie). Wg pracy B. I. Gonczarienko, L.N. Zacharow, W.E. Iwanow, W.A. Kirszow [3]

O dane eksperymentalne

—— krzywa teoretyczna

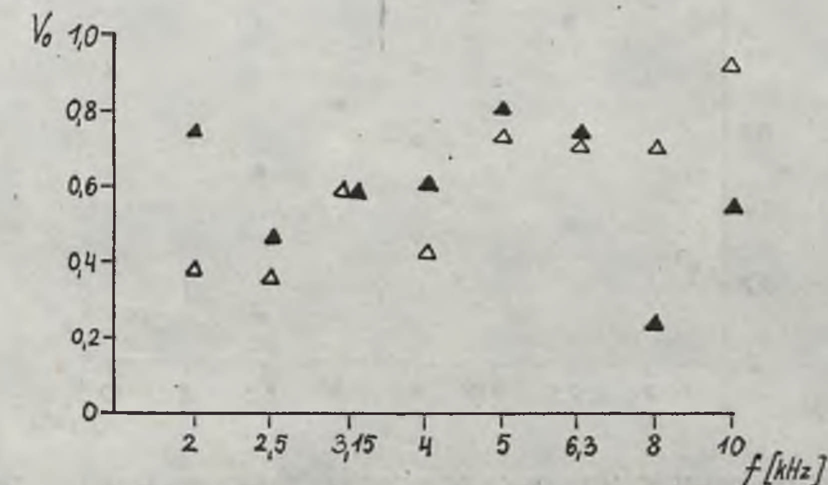


Fig. 8. Experimental absolute values of reflectivity for very fine sand, versus frequency of acoustic wave, at two angles of incidence

Δ data obtained for $\vartheta_1 = 0°$

▲ data obtained for $\vartheta_2 = 25°$

Ryc. 8. Eksperymentalne wartości modułu współczynnika odbicia od piasku bardzo drobnoziarnistego w funkcji częstotliwości fali akustycznej dla dwóch kątów padania

Δ dane otrzymane przy $\vartheta_1 = 0°$

▲ dane otrzymane przy $\vartheta_2 = 25°$

results, might have been due to too wide increments in the frequency scale.

The variation of reflectivity for different angles of incidence of acoustic waves at the bottom is illustrated in Figs. 8 and 9 by the examples of two angles selected for both macrofauna and very fine sand, i.e. $\vartheta_1 = 0°$, $\vartheta_2 = 15°$, and $\vartheta_1 = 0°$, $\vartheta_2 = 25°$, respectively. The absolute reflectivities, averaged over the whole range of frequencies for the four angles are:

macrofauna	$\vartheta_1 = 0°$	$V_o = 0.59$
	$\vartheta_2 = 15°$	$V_o = 0.80$
very fine sand	$\vartheta_1 = 0°$	$V_o = 0.61$
	$\vartheta_2 = 25°$	$V_o = 0.57$

According to the general theoretical relationship [2, 9], the data obtained in this study point to the growth of reflectivity with the increasing angle of incidence of the acoustic wave. From Figs. 8 and 9 it appears that the above relationship is satisfied in the whole range of frequencies for the macrofauna soil and in the 2... 6.3 kHz frequencies for very fine sand.

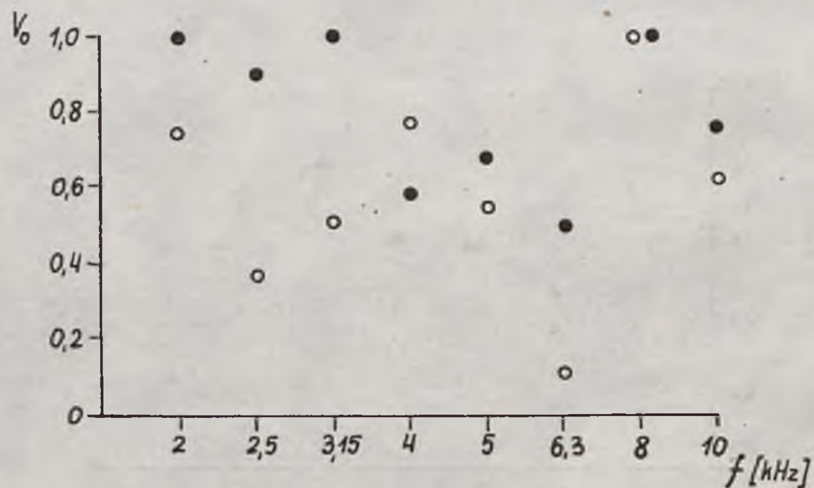


Fig. 9. Experimental absolute values of reflectivity from a sea floor consisting of macrofauna (molluscs, snails), versus frequency of acoustic wave, for two angles of incidence

○ data obtained for $\vartheta_1 = 0°$
● data obtained for $\vartheta_2 = 15°$

Ryc. 9. Eksperymentalne wartości modułu współczynnika odbicia od powierzchni dna utworzonej z makrofauny (małże, ślimaki) w funkcji częstości fali akustycznej dla dwóch kątów padania

○ dane otrzymane przy $\vartheta_1 = 0°$
● dane otrzymane przy $\vartheta_2 = 15°$

The results for frequencies of 8 and 10 kHz for sand differ from the remaining findings. To find whether this deviation is due to a more complex relationship between reflectivity and the angle of incidence, coupled with selective absorption in a two-layer bed, or is caused by errors in measurements, is impossible because of the limited number of experimental data.

The measurement of reflectivity by the method of standing waves is one of the most accurate techniques. The errors caused by multiple reflections from a free surface and the sea floor have been estimated elsewhere [3]. In our experiments this type of error does not exceed 5 per cent. The determination of the extrema of standing waves is also easy, as shown in Fig. 10 a, b, c, d; the fluctuations of the signal received do not exceed 0.1V, while the difference between standing-wave maxima and minima reaches 0.4... 0.5 V. Hence, the accuracy of determination of acoustic pressure at the maxima and minima of the field of interference is basically equivalent to the accuracy of voltage read-out on a voltmeter scale

5. CONCLUSIONS

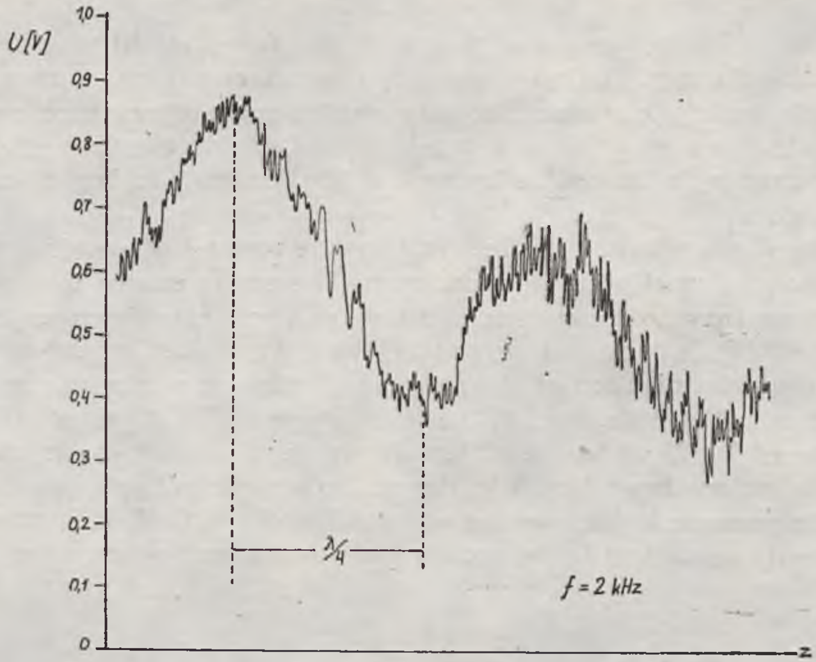
1. The figures obtained for the sea-floor reflectivity in the south Baltic are comparable with data for other water bodies and are contained within the limits given by other authors for similar types of sea floor.

2. In the case of normal incidence of acoustic waves the average absolute values of reflectivity are 0.55 for fine sand, 0.61 for very fine sand, and 0.59 for macrofauna.

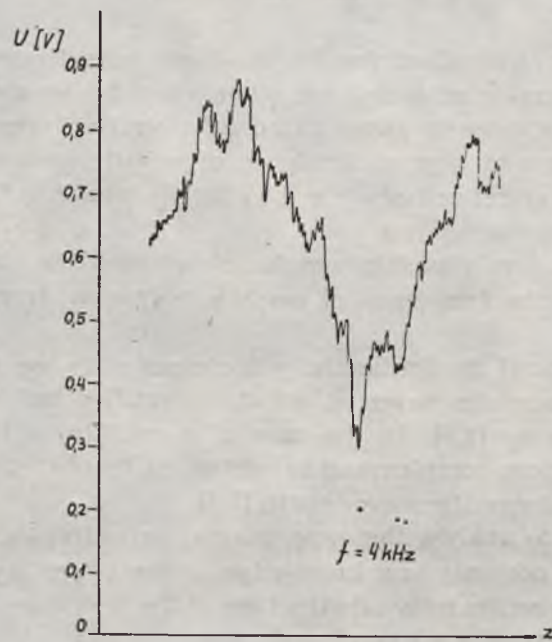
3. No distinct relationship was found between the absolute value of reflectivity and the frequency of acoustic waves in frequencies of 2... 10 kHz.

4. It was found that reflectivity increases with the increasing incidence angle of acoustic waves on a flat unstratified bed, which confirms the existing theory [2,9]. In the case of a multilayer bed this dependence is much more complex and is controlled by characteristics of individual layers and acoustic wave-length [1,4].

5. In order to analyse the experimental reflectivities for various sea floors correctly not only is a knowledge of the upper layer of the floor important, but also the internal structure of the bed, especially if acoustic signals of high intensity are employed.



U [V]
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
λ/4
f = 2 kHz
z



U [V]
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
f = 4 kHz
z

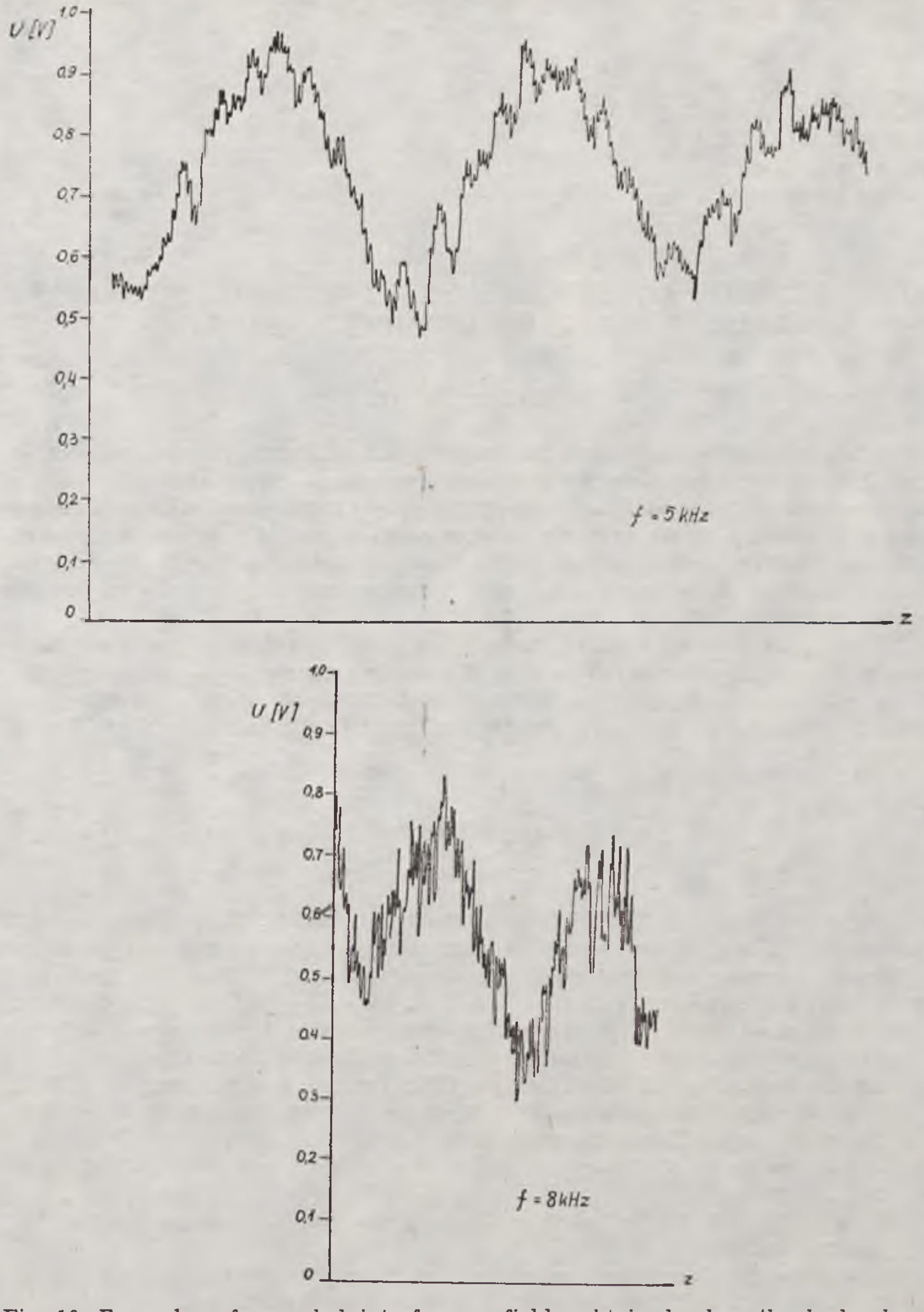


Fig. 10. Examples of recorded interference fields, obtained when the hydrophone moved along the z-axis (vertical axis oriented upwards from the bottom). The drawings correspond to various frequencies of acoustic waves

Ryc. 10. Przykłady rejestracji pola interferencyjnego otrzymane podczas ruchu hydrofonu wzdłuż osi z (tj. osi pionowej, skierowanej ku swobodnej powierzchni morza). Poszczególne rysunki odpowiadają różnym częstotliwościom fali akustycznej

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STRATY ENERGII AKUSTYCZNEJ PRZY ODBICIU OD WYBRANYCH RODZAJÓW DNA POŁUDNIOWEGO BAŁTYKU

STRESZCZENIE

Przedstawiono wyniki pomiarów współczynnika odbicia fal akustycznych od dna Bałtyku dla trzech rodzajów materiału osadowego i trzech kątów padania w zakresie częstości 2—10 kHz (w odstępach tercjowych). Dla piasku drobnoziarnistego o średniej średnicy ziaren 0,145 mm współczynnik odbicia od dna, uśredniony w całym zakresie częstości, wynosi 0,55, dla piasku o średnicy 0,12 mm—0,61 mm i dla materiału złożonego w przeważającej części z makrofauny (*Mytilus edulis, Cardium lamarcki, Macoma balthica*) — 0,59.

Przytoczone wartości określają maksymalne straty energii akustycznej otrzymane przy prostopadłym padaniu fali na dno. W zakresie częstości 2—10 kHz nie zaobserwowano wyraźnej zależności częstotliwościowej. Uzyskane wartości współczynnika odbicia zbliżone są do rezultatów otrzymanych przez Grubnika [2] dla Morza Kaspijskiego.

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