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# The examination of the structure of the upper layers of the seabed by the means of the parametric sonar

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## ABSTRACT

The acoustic methods as a non-invasive and teledetective are very good tools to study the stratification of bottom sediments, particularly useful as a research tool is a parametric sonar, which works together with other acoustic devices used for underwater observation, such as multibeam sonars and side scan sonars. Using the techniques of synthetic apparatus they can provide relatively a lot of information about the shape and the structure of the seabed. The results of the sounding of the bottom of the Gulf of Gdansk and the Southern Baltic Sea will be presented in the paper. Also there will be shown the pictures of both the seabed bathymetry and the profile of the stratification of the upper sphere of the seabed. These results have been precisely located in the geographical coordinates and compared with the results of geological investigations in the same area.

## INTRODUCTION

In subbottom surveys, acoustic techniques are primarily used to determine subbottom geometry. The composition is usually determined by taking sediment cores or samples. The costs of these surveys would be significantly reduced when remote, acoustic techniques could be used to classify the subbottom composition. Several methods exist based on features [2, 3], empirical relations [4, 5] or parametric models [6]. The problem is, that the precision and accuracy of these methods is largely unknown.

The large diversity of seabed characterization techniques creates problems with using them in a complementary manner, each technique provide an image of the sea-bottom that is filtered by the technique itself [1]. Several published experiments and studies have already shown that coupling different approaches may improve the understanding of seafloor geoacoustic properties and physical mechanisms.

Sonars used for the observation of the seabed, including the side and multibeam sonars, enable receiving the information about the shape of the seabed and objects lying on it. Despite their impressive resolution, it is impossible to obtain information neither about the stratification of the sediments nor about the objects buried in the seabed. Since the attenuation of the elastic wave is much higher in sediments than in the water, the waves that are of relatively high frequency are not able to penetrate the bottom sediments. Waves of relatively low frequencies can propagate deeper into them. A device producing waves on the basis of the parametric effect enables the enlargement the possibility of studies of the seabed stratification and searching for objects buried in the seabed. In general, the phenomenon can be described by two waves, which are propagated in the same area and their wave vectors are parallel to each other. The frequency of these waves is high enough to produce so called secondary waves, including the wave of the frequency equal to the difference of frequencies of primary waves, called sometimes the difference frequency wave. Generated wave has the characteristics of primary waves including width of the beam pattern and depth resolution, which determined the spatial resolution.

The paper shows the characteristic features when the data on bottom properties are collected by means of three different technique: side scan sonar, multi beam echosounder and parametric sonar. The data were obtained experimentally in the Gdansk Gulf in summer 2008 and 2009.

## THE SIMPLIFIED THEORETICAL DESCRIPTION OF THE PHENOMENA OF THE PARAMETRIC GENERATION OF THE ELASTIC WAVES IN WATER

The principle of parametric wave generation is a nonlinear interaction of two collinear waves of high intensity propagated in the same direction. Before describing the generation of the waves including the generation of the low frequency wave, the substance of nonlinear propagation of the wave will be presented by showing the example of harmonic wave of high frequency. Nonlinear properties of the environment, especially the ones described by the equation of the state of the medium, that connect the pressure and the density of the medium cause that the propagated wave of the finite amplitude is distorted. This distortion increases to a certain point causing that apart from the original wave, called primary one, appear secondary waves of frequencies that are multiple of the original frequency of the primary wave.

Theory of parametric wave generation is very complex. It leads to the equation derivated from the general law of mass conservation, law of conservation of momentum in the form of the Navier-Stoke's equation, the equation of state and the equation of energy. After a number of simplifications the relatively simple equation called the KZK is received (KZK – from the surnames of Khokhlov, Zabolotskaya and Kuzniecow). This is still a complex equation, however, relatively friendly for receiving some numerical solutions for the certain boundary conditions. In this paper, to illustrate the parametric effect the simplified form of KZK equation, called Burger's equation, was used:

$$\frac{\partial p'}{\partial x} - \frac{\varepsilon}{\rho_0 c_0^3} p' \frac{\partial p'}{\partial \tau} - \frac{b}{2\rho_0 c_0^3} \frac{\partial^2 p'}{\partial \tau^2} = 0 \qquad (1)$$

where:

$x$ - the axis perpendicular to the plane of the radiation

$p'(\tau)$ – the dynamic component of the pressure of the elastic wave

$p_0$ – static pressure in the medium

$\tau = t - \frac{x}{c}$ – time retarded

$\varepsilon$ – the coefficient of nonlinearity of the medium

$\rho_0 c_0$ - the density and wave speed in the equilibrium medium

$b$ - the coefficient of linear dissipation of the wave energy

The solution of equation (1) is sought by the perturbation method:

$$p' = p_1 + p_2 \qquad (2)$$

The solution could be obtained for $R_{ea} < 1$ (where $R_{ea} = \frac{p}{b\omega}$, $\omega$ - the angular frequency of wave) which indicates the little influence of nonlinear effects. The value $R_{ea} >> 1$ is characteristic for the high wave distortion.

If it has been assumed that the boundary condition will be in the following form for $x = 0$

$$p_1(x_1\tau) = p_{01} \sin \omega_1 \tau + p_{02} \sin \omega_2 \tau \qquad (3)$$

where: $p_{01}$ – the amplitude of the wave of the angular frequency $\omega_1$, $p_{02}$ – the amplitude of the wave of the angular frequency $\omega_2$

the part of the solution received for the equation (1) under the conditions (3) and the assumption (2) describing only the difference frequency wave is as follows:

$$p_2(x\tau) = \frac{\varepsilon p_{01} p_{02} (\omega_1 - \omega_2)}{2b\omega_1\omega_2} \left[ e \frac{b(\omega_1^2 + \omega_2^2)}{2\rho_0 c^3} x - e \frac{b(\omega_1 - \omega_2)^2}{2\rho_0 c_0^3} x \right] \qquad (4)$$

for $\omega_1 > \omega_2$

On the basis of the equation above the pressure of the wave of frequency equal to the difference between frequencies of primary waves can be estimated. The beam of secondary wave combines advantages of primary waves, narrow beam pattern and advantages of the low frequency wave, relatively low sound energy attenuation in the sediments. Those features allow to obtain sound beam of a good spatial resolution that is able to propagate into sediments. Basing on nonlinear acoustics theory, describing the generation of the difference frequency wave, parametric sonars and echosounders are designed.

## MEASUREMENT SET UP

The bottom structure was investigated using the parametric echosounder. It is a non-linear transducer source which simultaneously transmits two signals of slightly different high frequencies at high sound pressures. Nonlinear interactions generate new frequencies in the water, one of them being the difference frequency that has a bandwidth similar to the primary frequency. Both the primary HF signal (100 kHz) and the secondary LF signal (6 to 15 kHz) are recorded. Penetration can reach up to a few tens of meters in soft sediments. Advantages of the parametric acoustic system include (1) small beam width at low frequencies, (2) deep penetration with high resolution of sediment layers and objects, and (3) accurate depth measurements with the high frequency signal.

The parametric echosounder (Fig. 1) is the main part of the measuring system additionally equipped in several indispensable devices to ensure the great quality of measurements, as well as high accuracy in positioning of the vessel. It is used in combination with a motion sensor (MRU-Z, Kongsberg) to correct for swell movement. Data processing is carried out with the processing software "ISE 2.9" which allows layer editing and export to ASCII data, extended signal processing, data conversion and data export, tide, water sound velocity, and GPS z-level correction.

**Figure 1.** SES-2000 compact echosounder

Measurements are done from the boat that is navigated using the differential Global Positioning System (DGPS). The average navigational accuracy is estimated to be better than 1.5 m. Moreover, the position was controlled using radar Nobeltec operating with Visual Navigation Suite Admiral MAX. Additional equipment, such as the Automatic Identification System AIS, the NOAA (National Oceanic and Atmospheric Administration) weather station, or Navtex receiver, serves to ensure safety during research at sea, monitoring navigational and meteorological warnings.

Sea bottom investigation in the Gulf of Gdansk is carried out using two complementary devices parametric echosounder and multibeam echosounder. Both of them are equipped with GPS and Heading as positioning system, and with the MRU-Z system compensating the impact of the vessel's movement on results of measurements. In few cases also side scan sonar was used in investigations.

The area of research is shown in Fig. 2.

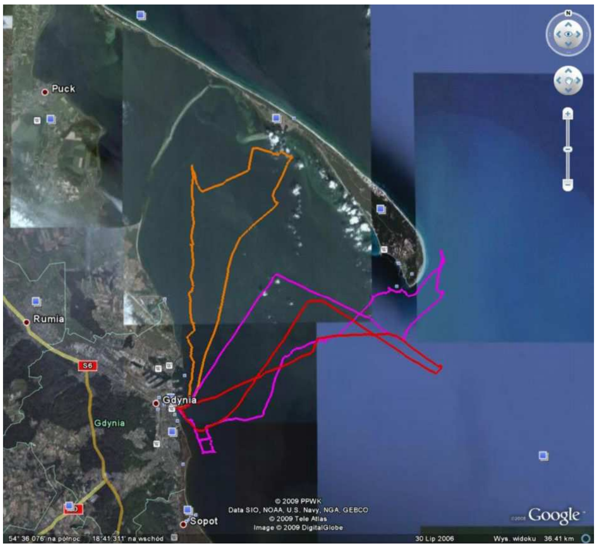


**Figure 2.** Map with selected measurement tracks

## RESULTS OF INVESTIGATIONS

The main goal of these investigations was to determine the structure of the seabed for different places of Gulf of Gdansk.

The diversity of seabed characterization techniques caused problems with using them in a complementary manner. Each technique provides an image of the sea-bottom that is filtered by the technique itself.

### Side scan sonar technique

The following figures show the characteristic features when the data on bottom properties are collected by means of different techniques. The three consecutive graphs illustrate the advantages of a side scan sonar in imaging of the shape of the bottom. The side scan sonar is an efficient tool to create an image of large areas of the sea floor. This tool is used for mapping the seabed for a wide variety of purposes.

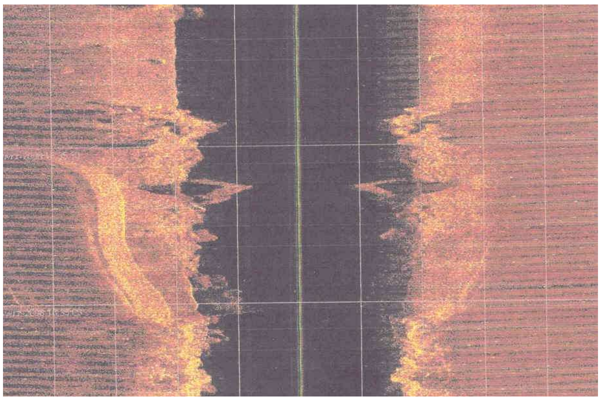

**Figure 3.** The image obtained directly from side scan sonar

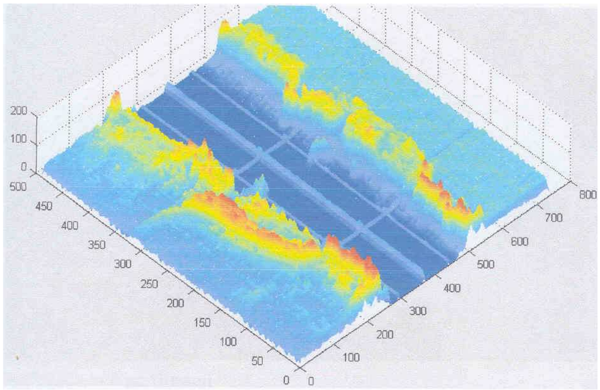

**Figure 4.** The same data as in Fig. 3 in 3D form

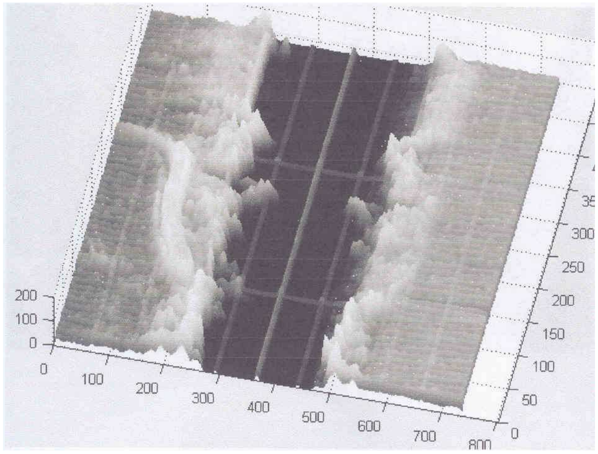

**Figure 5.** The same data as in Fig. 3 in 3D form in grey scale

### Data visualisation from multibeam echosounder

A multibeam echosounders, higher frequency systems are suitable for high-resolution mapping in shallow water and such systems are widely used for shallow water hydrographic surveying in support of navigational charting. Multibeam echosounders are also commonly used for geological and oceanographic research.

The Fig. 6. shows seafloor surface visualisation in three dimensions for 254 beams. There was used whole colour scale from Matlab colourmap “jet” (RGB) to create an image. Therefore there are significant colour changes for small depth differences. It causes, that an image is quite more detailed and distinct. This example doesn’t take into account the geographical position, because it is used to show the way of seafloor surface visualisation, therefore an image isn’t true equivalent of reality. Seafloor surface with geographical position is shown in Fig. 7.

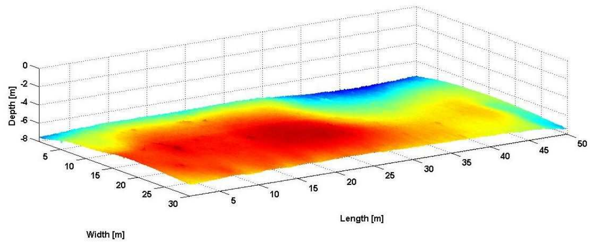


**Figure 6.**. Seafloor surface visualisation by multibeam echosounder EM3002


**Figure 7.** Imaging of seafloor surface from multibeam echosounder superimposed on satellite image from Google Earth

## Parametric sonar images

The special features of parametric generation of sound beam allow to penetrate the bottom for much more then several meters. Data collected during observation allow to assess the penetration properties of the equipment.

High-resolution sediment-echosounding allows distinguishing between sediment layers of different impedance. In the Gulf of Gdansk most common is an echogram characterized by numerous distinct, closely spaced and continuous parallel horizontal reflectors. There are particularly strong major reflectors within the vertical sequence which can be traced over several kilometers distance (Fig. 8). Acoustic penetration was at given conditions of about 30 meters. The fine structure of deeper layer of sediments is reflected in the image.

The depth of penetration depends on geoacoustic parameters of bottom sediments. For sediments of great acoustic impedance and at the same time great attenuation parametric beam reach only few meters depth below water- sediments border, as it is shown in Fig. 9

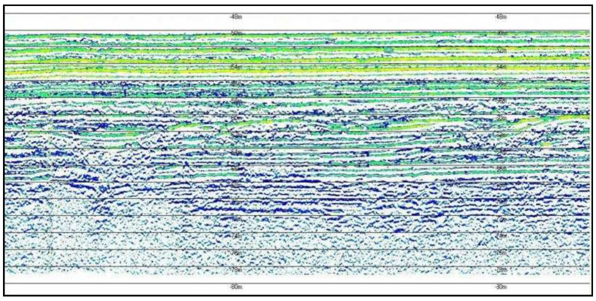

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**Figure 8.** Seabed structure typical for many areas in the Gulf of Gdansk region

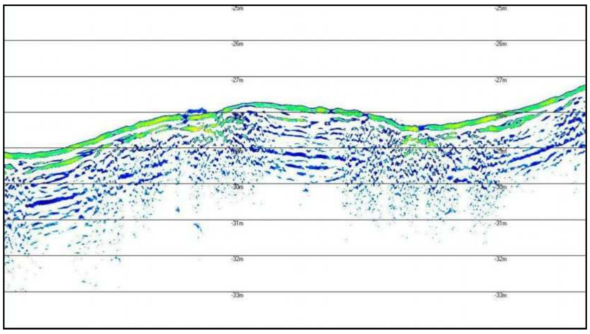

**Figure 9.** Structure of upper layer sediments of bottom composed of well reflected material

The parametric echosounder allows to carry out geological research of the upper layer of the seabed remotely. An interesting example of rapid change in the seabed structure is observed in the part of the Gulf of Gdansk known the Puck Bay (Fig.10). This way, spatial distribution of the seabed sediments could be established more precisely than by any other method of seabed investigation

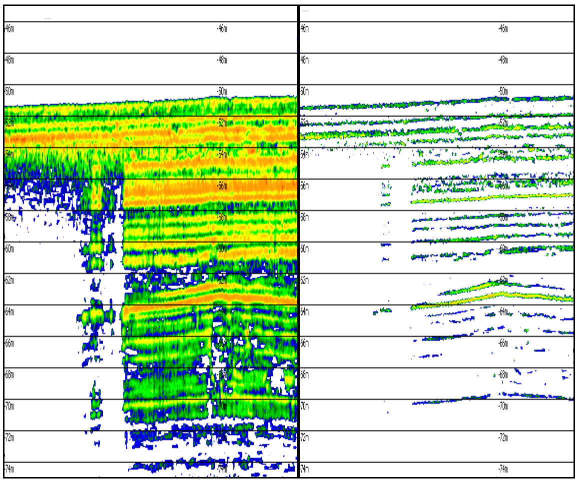

**Figure 10.** Results of *in situ* trials results – images of the bottom structure obtained by means of different methods of echogram presentation; bottom depth -50 m; sediment penetration up to 24m

## CONCLUSIONS

Taking into account the experimental results, following conclusions can be drawn. The parametric echosounder is a good tool for examination of the acoustical feature of the sea bottom up to tens meters. The depth of penetration depends on the geoacoustic parameters of the seabed sediments. The acoustic beam penetrates the seabed with the resolution good enough to evaluate the layered structure of the sea bottom and to look for objects buried in the sediments.

## ACKNOWLEDGMENTS

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