CONDITIONS FOR PROPAGATION WAVE OF FINITE AMPLITUDE IN THE SOUTHERN BALTIC

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In order to improve the buried objects search capability, there is a need to investigate new techniques that will enable the detection, localisation and classification of buried mines. Indeed, mines buried in marine sediments represent a severe threat, especially in coastal waters. Moreover, an inventory of objects buried in harbour areas is necessary to assure the security of ships. Parametric sonars are the new class of devices that allow to penetrate the sea floor. However their efficiency depends strongly on natural conditions in the sea. The dependence is of great importance in the shallow sea with considerable changes of acoustical conditions during the year. The paper contains the results of research of effectiveness of nonlinear wave generation in the Southern Baltic conditions basing on in situ measurements of the hydrological parameters.

INTRODUCTION

The knowledge of the structure and composition of the upper sediments of the sea bottom is of great importance for acoustic propagation studies. The traditional method for collecting such as geological information is through *in situ* sampling (e.g. coring) of the sea bed. However, this method is time consuming and expensive, whereas it supplies only very localised point samples, and still involves a fair amount of interpretation before these data can be used in acoustic propagation predictions. Sea bed reconstruction by acoustic means offers an efficient alternative to traditional sampling and in this connection it is a topic of much interest in the underwater acoustics. The development of methods using finite amplitude waves for the recovery of structure and composition of the sea floor from acoustic data is one of the most promising.

Namely, parametric sonar is finding as the effective tool in the area of shallow water. The biggest problem facing active sonar in the shallow water is reverberation. Shallow water active systems are not usually limited by ambient or system noise. The difficulty is that the bottom and surface interaction is so strong that backscattering from these surfaces dominates the return echo. This effect scales with output power, so cannot be easily overcome. One way to fight this reverberation is to transmit the signal in a carefully controlled beam with little or no spatial sidelobes. Traditional beamforming requires large apertures to achieve low sidelobes, and this results in large and unwieldy transducer arrays.

Parametric sonar relies on the nonlinear interaction of two high frequency and high intensity signals to produce a lower frequency wave. The sidelobes of the low frequency wave do not exceed those of the (much higher frequency) transmit signals.

Relaxation processes quickly absorb high frequencies, so that in the far field, only the (desired) low frequency wave remains.

Using parametric sonar, highly collimated beams can be directed into the bottom and sub-bottom to detect buried or partially buried mines. Parametric beams can also be used to search the bottom structure or the water column, steering the beam like a narrow torchlight through the region of interest without incurring blinding backscatter from energy, which leaks into angles which interact strongly with the surface or bottom.

Specific features of those devices, known as parametric antennas, extend prospects of underwater exploration. However, it must be taken into account, when applying them, that there are more environmental factors that have impact on the result of investigation than in case when only traditional linear devices are used.

It is known that sound propagation in shallow water is much more complex than in the ocean. Propagation of the wave of infinitesimal amplitude depends chiefly on changes in the sound speed distribution. Propagation of the finite amplitude wave depends also on spatial distribution of the nonlinear parameter *B/A* as well as on the attenuation coefficient. All of them are influenced by variation in temperature and salinity, but the first and the second depend strongly on temperature whereas the third – the attenuation coefficient - on salinity. Except the environmental properties, the important factors having an impact on the course of nonlinear interaction phenomenon are parameters of the source of primary wave, the pressure amplitude and the frequency. The efficiency of nonlinear transfer of energy from the primary wave to the higher harmonic components could be characterised by the value of the product, in which all main factors influencing the nonlinear wave propagation are contained:

$$\varepsilon \operatorname{Re}_a = \left(\frac{1}{2} \frac{B}{A} + 1 \right) \frac{\omega v_o}{2 \alpha_o c_o^2} \tag{1}$$

where ε is the nonlinear coefficient, ω is the angular frequency, v_o is the velocity, α_o is the attenuation coefficient, and c_o is the speed of sound. The value of the product is inversely proportional to the attenuation coefficient.

ACOUSTIC CLIMATE OF THE SOUTHERN BALTIC

The conditions of the acoustic wave propagation in the southern Baltic are much more complex than in other shallow waters. In the typical shallow water seasonal changes in acoustical conditions in the upper layer of the depth of about 60-70 m are observed. They are caused by variation of the annual meteorological conditions. Most often, in the deep water layer acoustical conditions are stable throughout the year. However, in the Southern Baltic they change during the year also in the deep water layer. They depend on the inflows of highly saline water from the Northern Sea through the Danish Straits, which evoke dense bottom current increasing the salinity at the bottom. The difference in the vertical sound speed distribution in the Southern Baltic and the other shallow water could be noticed when the data presented in Fig. l are compared.

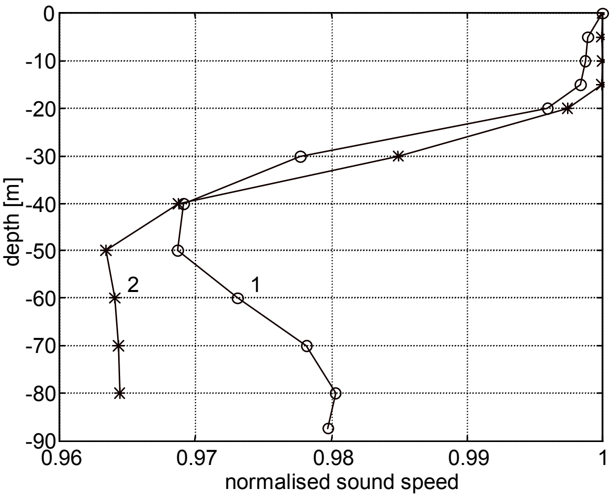

Fig. 1. Normalised profiles of sound speed for summer in the Baltic Sea (1) and in a typical shallow sea (2)

The differences are also visible in the changes in the absorption coefficient. In the typical shallow water with high salinity and stable deep water layer seasonal hydrological changes involves changes in the absorption coefficient in the upper layer as a consequence of the changes in temperature of water. Specific conditions of the Baltic Sea reveal themselves in considerable growing of the value of the absorption coefficient with the depth in the deep water layer during whole the year. The changes in the value of that parameter, caused by changes in temperature, observed in the upper layer are smaller than the differences occurring between values at the surface and at the bottom.

Absorption of the wave energy is strongly dependent on the frequency of the wave. It is illustrated by examples shown in Fig. 2, where absorption parameter is evaluated for the hydrological condition typical for the Gdansk Deep region for two frequencies of wave: 20 kHz and 100kHz.

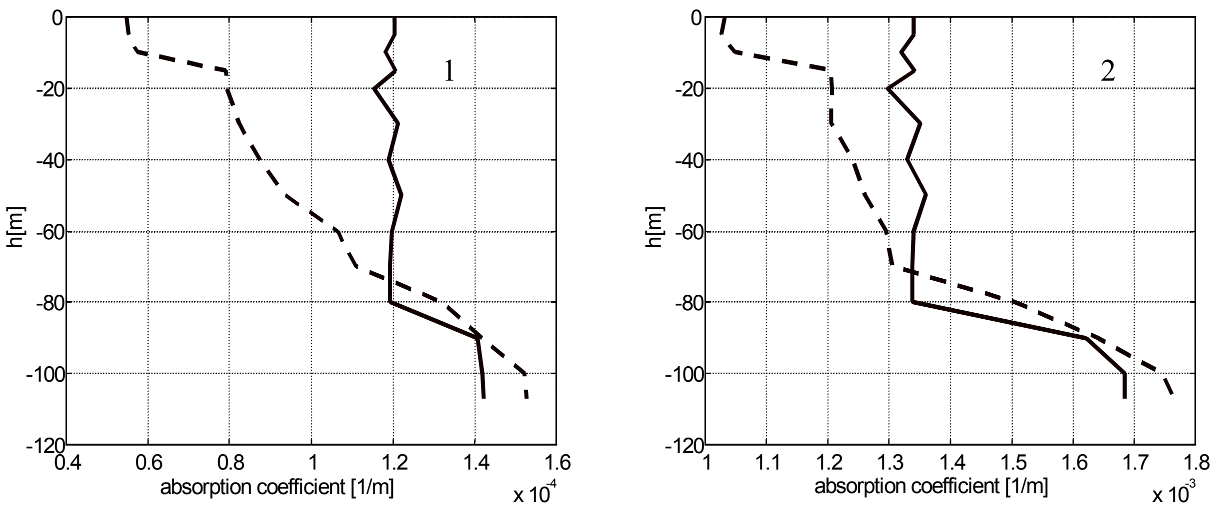

Fig. 2. Changes in the absorption coefficient in the Gdansk Deep region in March (**—**) and in August **(- -)**: 1 – f= 20 kHz, 2 - f = 100 kHz

CONDITIONS FOR FINITE AMPLITUDE WAVE PROPAGATION IN THE BALTIC SEA

Mechanism of the nonlinear wave propagation is more complex than the linear one. The phenomenon is influenced not only by the sound speed distribution but also by nonlinear and absorptive properties of the medium.

Nonlinear properties of the sea are characterised by the nonlinearity parameter B/A, that is a function of temperature, salinity and static pressure. Because the main factor influencing it, similarly as the sound speed, is temperature, the shape of line illustrating vertical distribution of the nonlinear parameter B/A is close to the shape of the line showing the distribution of the sound speed. An example of the vertical distribution of the sound speed and the nonlinear parameter B/A obtained experimentally is presented in Fig. 3. As it was mentioned above the efficiency of the energy transfer from primary wave to harmonic components arising while wave propagation could be assessed using the value of expression (1). Therefore, the distribution of product $\varepsilon \mathrm{Re}_a$ is placed together with the sound speed and the nonlinear parameter B/A distributions.

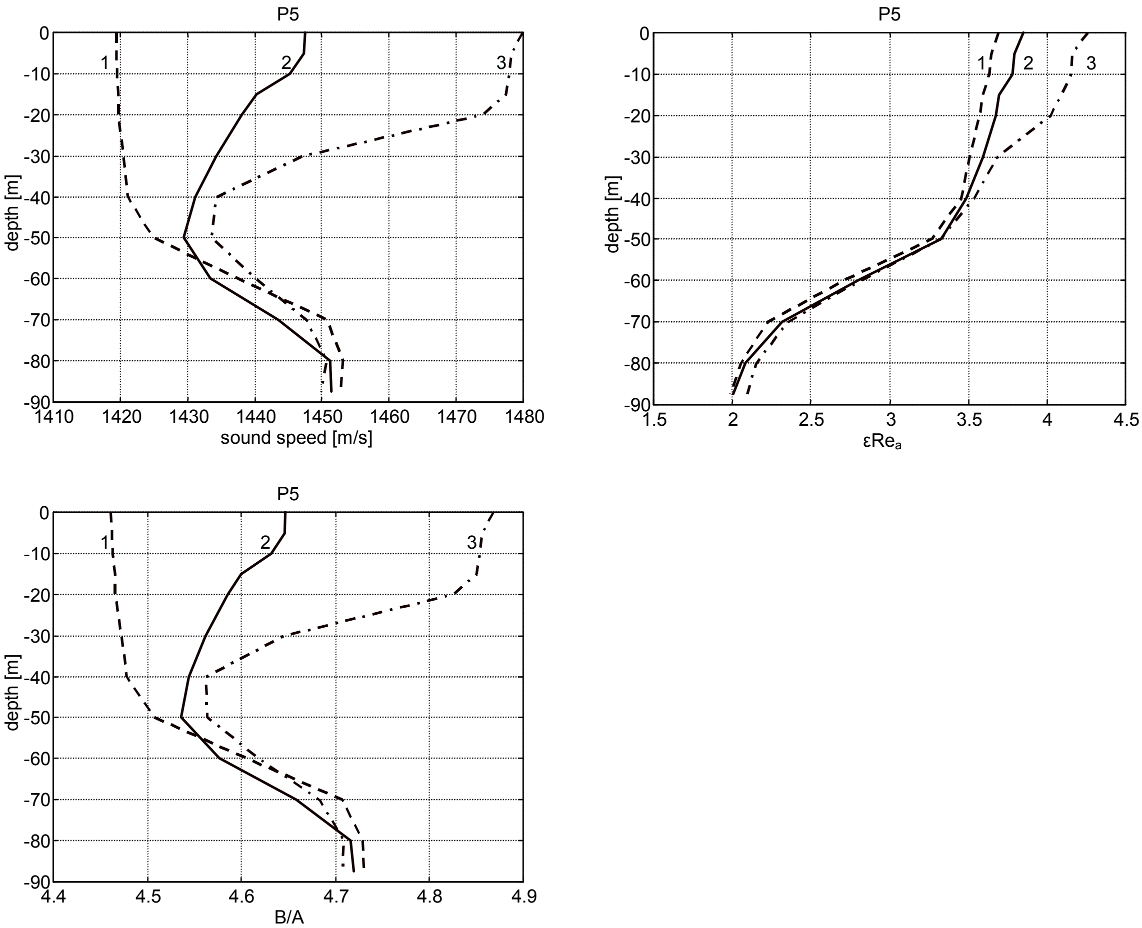

Fig. 3. The comparison of vertical distribution of the sound speed, nonlinearity parameter B/A and ε Re_a determined for the same hydrological conditions in the Bornholm Deep: *f=100 kHz, v_o=0.01 m/s*

The impact of the absorption on the value of ε Re_a reveals itself in change in the trend of the function in the deep water layer when compared to other parameters in Fig. 3. The annual variation of the value of product $\varepsilon \, Re_a$ is observed chiefly in the upper layer and is not as considerable as in sound speed or nonlinear parameter distributions. It affects harmonic component generation.

To assess nonlinear generation of wave in conditions typical for the Southern Baltic a numerical prediction has been worked out basing on plane wave model of finite amplitude wave propagation. The real distributions of hydrological and acoustical parameters obtained experimentally are used in calculations. Changes in the primary wave and its second harmonic pressure amplitudes, which were obtained assuming weak nonlinear interaction, are presented in Fig. 4. It was also assumed that the parameters of the source (frequency and velocity) are invariable during whole year.

Estimated roughly, the growing of the nonlinear distortion is nearly the same during the whole year. The increase of pressure amplitude of the second harmonic is slightly bigger in summer. However, to obtain proper prediction of the course of nonlinear distortion in natural conditions real vertical distribution of hydrological and acoustical parameters must be considered. The example shown in Fig. 4 describes the differences between predicted pressure amplitude obtained when the whole vertical distribution is taken into account or when only environmental parameters measured at the surface are used in calculation. In the considered case, the difference in pressure amplitude at the bottom is about 5% for the primary wave and about 15% for its second harmonic. Natural vertical changes in parameters influencing the nonlinear wave propagation decrease the pressure of the primary wave towards the bottom and at the same time increase the pressure of the second harmonic.

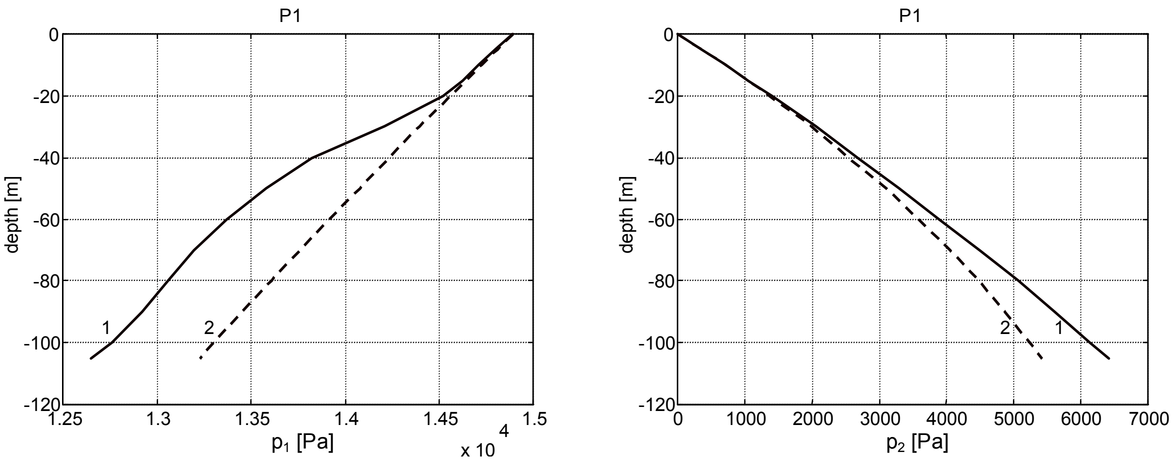

Fig. 4. Changes in the pressure amplitude of the primary wave and its second harmonic in the Gdansk Deep region in August: 1. prediction based on vertical distribution of acoustical and hydrological parameters, 2. prediction based on value of those parameters at the sea surface;
f=100 kHz, v_o=0.01 m/s

CONCLUSIONS

Conditions of the nonlinear wave propagation in the Baltic Sea are rather complex. To predict range and efficiency of nonlinear underwater devices in the Southern Baltic many factors have to be taken into account.

Temperature of water is the factor that has the strongest impact on the sound speed and the nonlinear parameter B/A. Therefore the spatial distribution of the parameter B/A in the Southern Baltic is similar to the temperature distribution and the sound speed distribution.

The absorption coefficient depends more than the nonlinearity parameter on salinity of the sea water and changes with the frequency. That is the reason why the spatial distribution of the value $\varepsilon \mathrm{Re}_a$ differs significantly from the spatial distribution of the sound speed and the parameter B/A.

Prediction of the growth of the nonlinear distortion based on values of acoustical and hydrological parameters measured at the sea surface differs significantly from the one obtained when real vertical distributions are taken into account.

In the investigation, the presence of gas bubbles has been neglected. In the Baltic Sea, that factor can influence the nonlinear propagation in the considered frequency range. The results of prediction could be changed in certain circumstances when the gas bubbles concentration is large enough to change the nonlinear properties of the water.

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