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DETERMINATION OF NAUTICAL DEPTH BY DENSITY MEASUREMENT AND BY ACOUSTIC SOUNDING

Abstract

Pilot investigations were carried out with the objective of testing the usefulness of measuring the density of the mud/water medium to determine nautical depths in the Port of Gdańsk. Results show significant differences between the nautical depth and the depth determined by acoustic methods at loose bulk cargo terminals. It was also found that too large depth values were obtained when 33 kHz transducers were used. Applicability of acoustic profiling for distinguishing structure of deposits which must be dredged was tested.

1. Introduction

Often, when decisions are being made on opening various water areas to navigation (approach channels, port basins) or to other unconventional uses (recreation, pleasure navigation, social, etc.), appears the problem of clear-cut determination of the nautical depth, defined as the depth below which the density of the water/mud mixture still allows safe navigation. In the West European ports a density of less than 1.2 t/m^3 is considered safe for navigation. In Polish ports, basically acoustic methods are used for measuring depth, and the frequencies used are mainly 210 kHz and sometimes 33 kHz and 457 kHz (e.g. the SeaBat 9001 multi-beam echosounder).

As Dutch investigations [1] have shown, traditional measurements by the acoustic method give too small depths, which results in larger volumes and higher costs of dredging to ensure the strucntural and guaranteed depth. On the other hand, use of 15 and 33 kHz frequency echosounders does not guarantee a clear determination of the safe nautical depth. This problem is illustrated in Fig. 1.

This problem is especially important in ports and water areas with high rates of natural and anthropogenic mudding. Experience of the Port of Rotterdam shows that implementation of the nautical depth determination method allowed to reduce costs of dredging from 100 million to 44 million DFl per year. Basing on problems with processing of data from acoustic soundings, the authors of this paper thought that the same phenomenon may occur

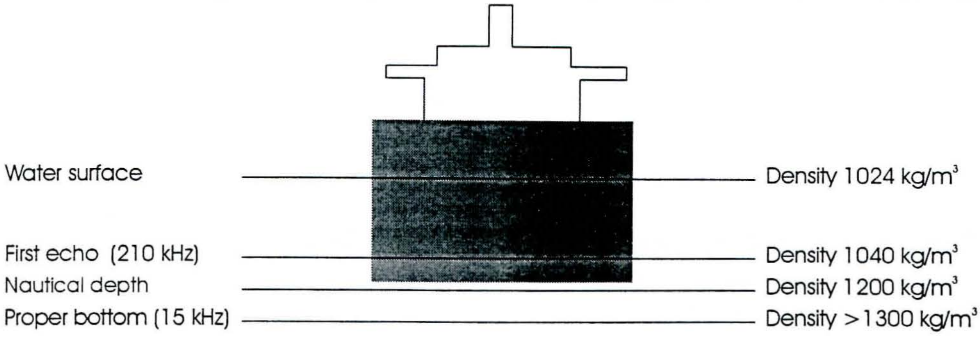

Fig. 1. Change of density of mixture and deposits in relation to nautical depth [1]

in basins at the Vistula Quay, and also at the Chemists' Quay and Coal Pier. The management of the Port of Gdańsk selected the areas shown in Fig. 2 for pilot investigations of the difference between acoustic and nautical depth.

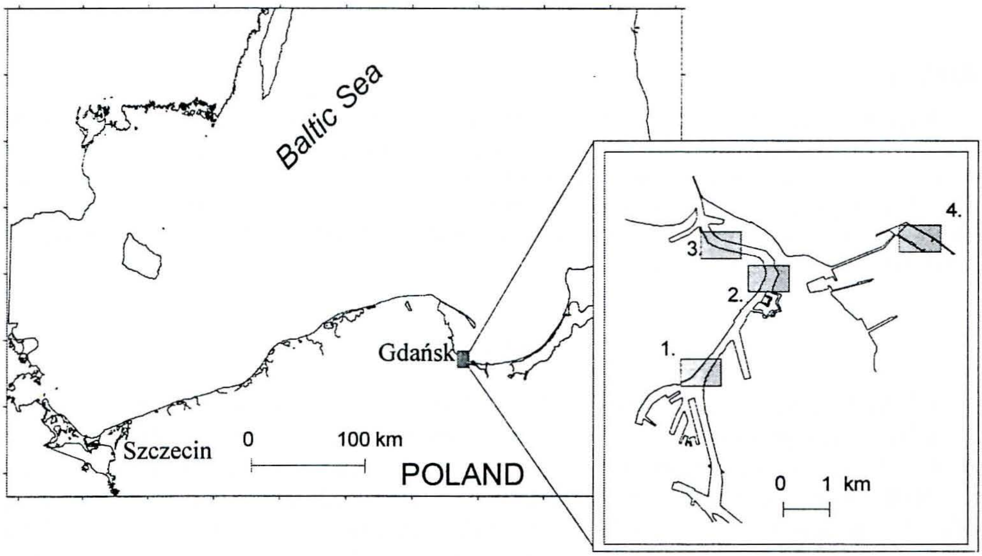

Fig. 2. Location of investigated areas: 1. Vistula river channel, 2. Oil Basin, 3. Chemists' Quay, 4. Coal Pier

A further problem, which will have to be solved in the near future, is the segregation of the dredged spoil. Because of the high cost of utilisation of contaminated spoil, distinguishing by acoustic methods, supported by traditional sediment sampling with cores, the layers of deposits with various levels of contamination seems well justified. Therefore, the main objectives of the work were to:

- evaluate if, in conditions of the Port of Gdańsk, accurate determination of the nautical bottom may reduce the volume and cost of dredging,
- make an initial assessment of the relationship between depths determined by echo-sounders with various frequencies and the nautical depth,

- check the effectiveness of acoustic methods for the distinguishing of deposit layers with different levels of contamination, and for calculating their volume,
- develop a method of determining the nautical bottom by an isotope method.

Because of the high cost of the apparatus for accurate determination of nautical depth, the realised program of investigations was of pilot project character, and allowed to apply for a research project, which currently is financed by the Polish Committee of Research.

According to the contract with the Port of Gdańsk Authority, the following measurements were carried out in the pilot water areas:

- seismoacoustic profiling along profiles located every 25 m, at acoustic wave frequencies: 5, 7, 10, and 14 kHz;
- traditional sounding with a double frequency echosounder (210 and 33 kHz) along the same as above profiles;
- acoustic sounding with multi-beam echosounders (SeaBat 9001 and EM 3000);
- measurement of the vertical distribution of the deposit/water mixture density using an isotope method;
- taking 4 cores in each of the water areas, in order to obtain a characteristic of the deposits.

The nautical depth is defined as that depth above which the density of the mixture of water and mud is sufficient for safe navigation of ships. The problem whether density is a sufficient parameter to determine safe navigation, is still discussed by some navigators. The manoeuvrability of a ship depends also on the properties of the mud, influencing the mud's resistance resulting from viscous friction, and on the generation of internal waves in the water/mud mixture. In most water basins, when a certain critical value is exceeded, stress in the mud increases significantly. In Rotterdam this threshold density is 1.2 t/m^3. At present two methods of measuring the nautical depth are used: the acoustic method and the isotope method.

1.1. The acoustic method

In Fig. 1, the effect of using echosounders with various frequencies is shown. By using a lower frequency transducer penetration through the mud can be increased.. The 210 kHz frequency produces reflections from mud with a density of 1.04 t/m^3. In an area with uniform mud the 15 kHz wave penetrates deeper than in the 1.2 t/m^3 density layer. But if the mud is nonuniform it is difficult to established what layer is represented by the reflection.

Because of that it is rather difficult to accept acoustic methods of measuring navigational depth as sufficient information. In practice, acoustic images are used only to show the upper boundary of the mud. Attempts at using a nonlinear echosounder using the relationship between the mud density and the parameters of the acoustic signal, also proved unsatisfactory due to the high complication of the relationship.

1.2. The isotope method of measuring density of the water medium

Because of the difficulties with using acoustic sounders in water areas with mud, an isotope method of measuring the density of the water/suspension medium was developed. The method consists in emitting by a source of radiation of a given dose of radiation, and in measuring that part of the radiation which passed through the medium.

At present two types of sediment density measurements with an isotope sounder are used: the stationary method and the method of continuous profiling. In the stationary method, the sounder with a source of radiation (an isotope of barium) is lowered at a constant speed from the water surface to the bottom. Due to its shape and mass, the sounder penetrates through the mud to given depth dependent on the compactness of the mud (Fig. 3). Because pressure, temperature and water salinity are measured simultaneously, and thanks to earlier carried out calibration procedures, it is possible to determine the density of the water/mud mixture. The negative side of the method is that data are collected only at separate points. In order to obtain information required for managing the dredging works, the data must be interpolated, and this justified only if the area is characterised by a uniform density.

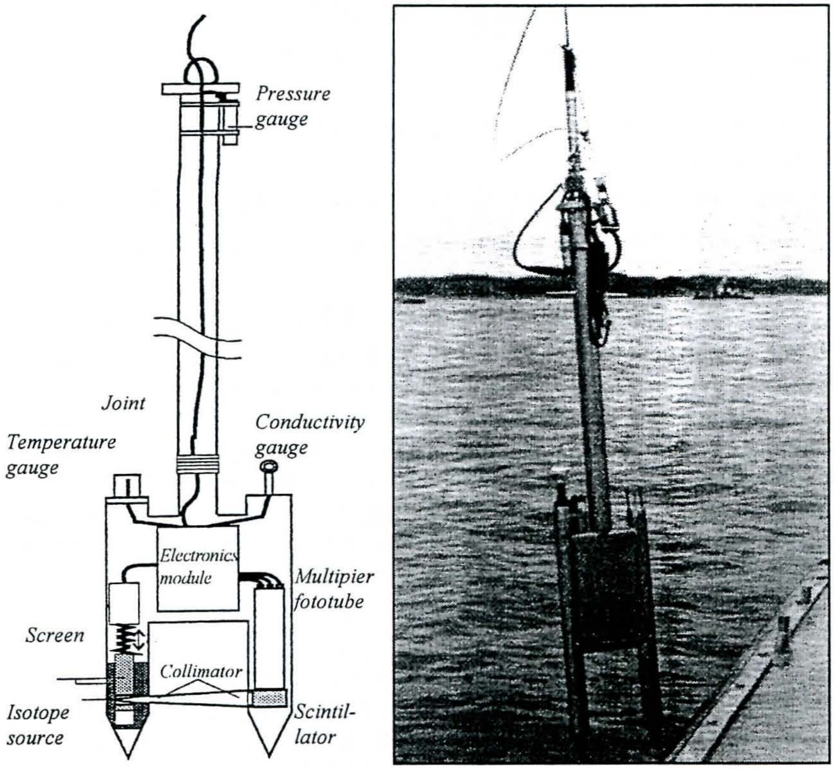

Fig. 3. Isotope sounder for measuring density of deposits

In the second method, the container with the radiation emission meter and the pressure, temperature and conductivity gauges are towed behind a ship. The sounder is lowered and oscillates between two horizons with preset densities. This allows to carry out routine measurements of the nautical depth as often as the traditional echosounder measurements are made. At present both methods are used on an operational basis, though still investigations to improve them are being carried out.

2. Results of nautical depth measurements in the Port of Gdańsk

Before proceeding with the principal measurements in the pilot areas selected by the Port Authority, point measurements were carried out in basins, in which significant differences between the position of the nautical bottom and the bottom obtain from echosounding were expected. In Fig. 4 are presented results of nautical depth measurements in Vistula river and at the Chemists' Quay. The point measurements showed a difference of 22 cm between the nautical and acoustic bottom in the river channel. The largest differences were recorded at the Chemists' Quay (95 cm). Point measurements in the approach channel to Gdańsk indicated a hard bottom with, no difference between nautical and acoustic depth.

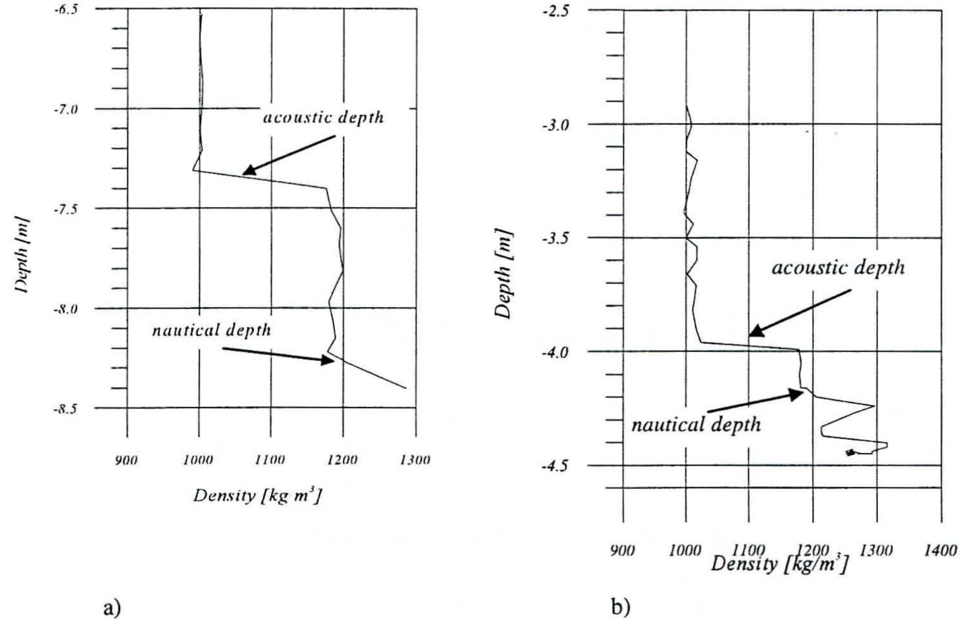

Fig. 4. Distributions of deposit density at the Chemists' Quay (a) and in the river channel (b)

In the pilot areas selected by the Port Authority, significant differences between the nautical and acoustic depth were found only at the Vistula Quay (Fig. 5). The average difference in that area was 11.1 cm. Assuming that the deposits are uniform between the measured points, this gives a volume of 1100 m^3 over an area of 1 hectare. Macroscopic investigations of a core taken in the area showed a complicated structure of the deposits at that quay, characterised by deposits of anthropogenic origin along the whole profile (mud and clay with layers of sulphur and coal).

Analysis of cores taken in the Oil Basin No. 1 showed that practically the whole profile, except a 4 cm layer of organic deposits, is built of coarse sand with some cobbles. The isotope sounder indicated hard bottom at this site. Hard bottom was also found practically at all measuring points along the Oliwa and Sulphur Quays. Cores taken at both these sites revealed river deposits (clay, mud and sand).

Test measurements of depth with the isotope sounder showed that in the investigated water areas, problems of mud accumulation are much less significant than in West European ports. This may be due to the much lower density of sea water, no tides to facilitate sedimentation, and to the fact that port basins are practically cut off from supply of suspended matter transported by the river. However, the difference between the nautical and acoustic depth cannot be neglected in the case of bulk cargo terminals (e.g. the Chemists' Quay, Coal Pier) and of the river channel.

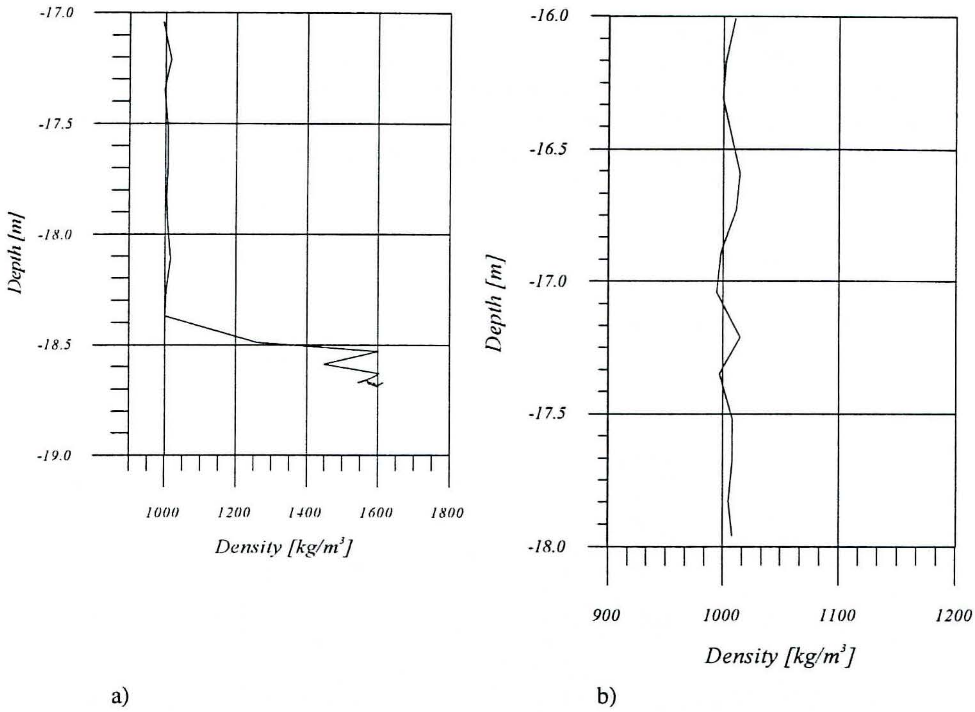

Fig. 5. Distributions of deposit density at the Coal Quay (a) and in the Oil Basin (b)

3. Relationship between the depth determined by acoustic method and the used wave frequency

Experience of the authors with processing data from bathymetric measurements made with echosounders using a range of frequencies showed, that often differences between bathymetric plans are the result of using in the acoustic systems different acoustic wave frequencies. One of the objectives of the pilot project was to asses the scale of these differences. Therefore in four water areas indicated by the Port Authority bathymetric measurements were carried out using a SeaBat 9001 multi-beam echosounder (457 kHz) operated by the Maritime Institute and a SIMRAD EM3000 multi-beam echosounder used by the Gdańsk Port Authority. The average error of depth difference on the maps made using both these echosounders was 1 cm, and standard deviation of these differences was 1 cm. As expected, slightly smaller depths were indicated by the SeaBat 9001 apparatus. In the whole pilot area depth differences obtained from both multi-beam sounders did not exceed 0.6 metres, i.e. they were within the limits permitted by IHO Standards. Over most of the water area, these differences did not exceed 10 cm. There are grounds to suppose that the real error of the differential map was two times smaller.

Very often, in order to determine the „hard bottom" in water areas with muddy bottom, two-frequency echosounders are used. Experiments carried out during these investigations aimed at showing the differences in depth measurements with most often used 210 and 33 kHz frequencies. As an example, in Fig. 6 are shown results obtained from a DESO 15 echosounder in two pilot water areas.

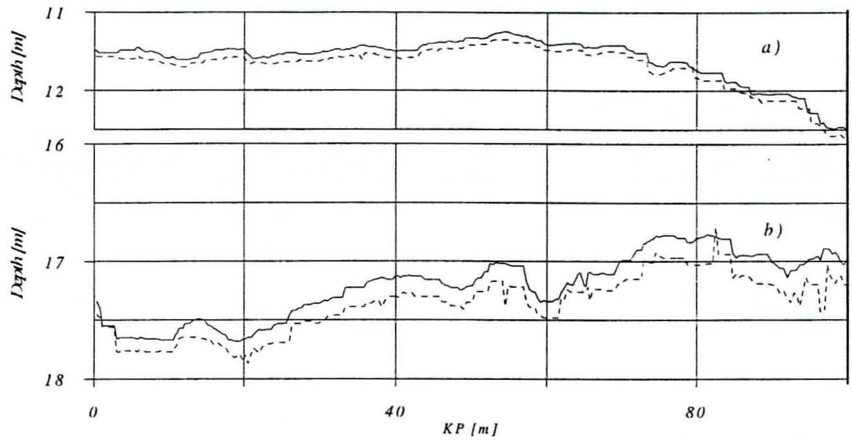

Fig. 6. Depth from echosounder 210 kHz (continuous line) and 33 kHz (broken line) (a) at the Oliwa Quay and (b) in the Oil Basin No. 1

Results of profiling confirmed that the 33 kHz frequency wave penetrates deeper into the bottom deposits. In three water areas: at the Oliwa Quay, Sulphur Quay and Vistula Quay, depths indicated by the 33 kHz echosounder were about 9 cm larger than obtained from the typically used 210 kHz echosounder. It probably may be assumed that in other areas of the Port of Gdańsk with similarly small rates of sedimentation processes, the differences are of the same order. Only in the Oil Basin the average difference between the two echosounders was about 18 cm. In this basin, as it was earlier mentioned, weakly compacted coarse and medium sand is present, at the same time the density sounder indicated nautical bottom directly at the upper surface of the sand layer.

The experiment shows that, for sounding for navigational needs, frequencies lower than 200 kHz should not be used, since they may indicate too large depths. The small intensity of sedimentation processes in areas proposed for the pilot investigations did not allow to investigate penetration with the 33 kHz frequency in a thicker layer of mud.

4. Possibilities of using acoustic methods for distinguishing layers of sediments in ports

As in West Europe, shortly also in Poland segregation of spoil dredged in ports will become necessary. The economical feasibility of such procedures results from the increasing cost of utilisation of the spoil, which when dredged by layers with similar degree of contamination, allows to reduce the volume of deposits requiring costly storage (e.g. in a special burial ground). An experiment was made to find if an acoustic method can be used for distinguishing layers of such deposits.

In all four pilot areas of the port seismoacoustic profiling was carried out, using a profiler with the following frequencies: 5, 7, 10, 12 and 14 kHz (ORETECH 3010S). The measurements proved that the adopted method allows to distinguish the layer of deposits with satisfactory for practical needs results (Fig. 7). The best effects were obtained when working with frequencies of 5 and 10 kHz, and the 10 kHz frequency provides better results.

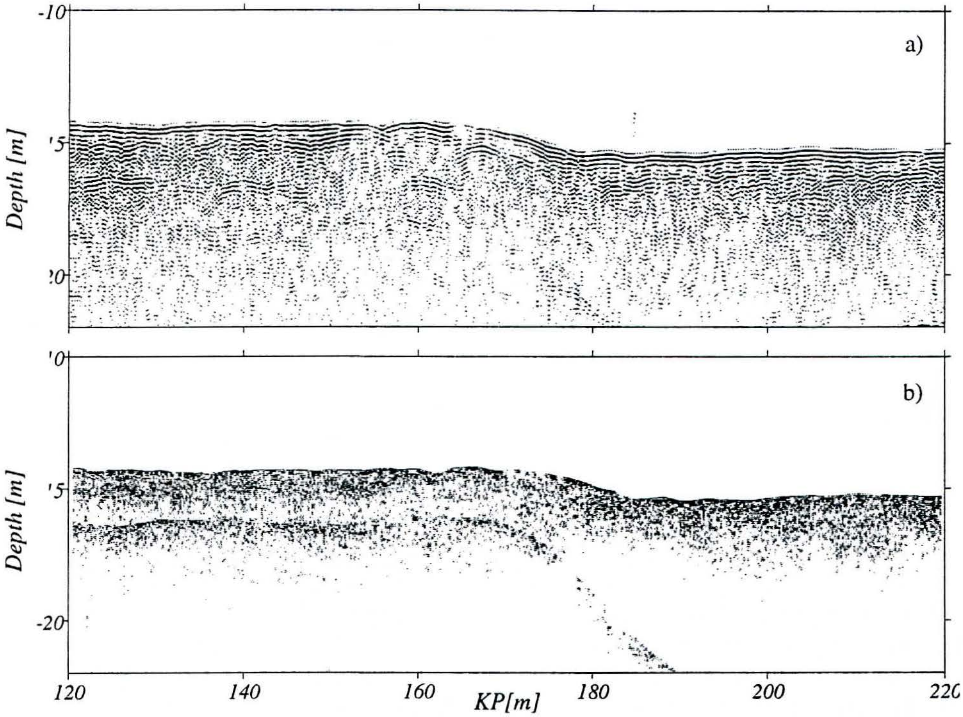

Fig 7. Example of a bottom profiler record at the Oliwa Quay (a) 5 kHz and (b) 10 kHz

5. Conclusions

The experiment showed that among the selected by the Port Authority pilot areas, intense sedimentation, suggesting that the isotope technique of nautical depth measurement may be feasible, occurs only at the Vistula Quay. On the other hand, point measurements made at the Chemists' Quay and at the Coal Pier showed that the phenomenon of too low depth indications from 210 kHz echosounders may reach values which justify the use of the isotope method of nautical depth determination.

Simultaneous measurements with multi-beam sounders with different frequencies (210 and 456 kHz) showed good agreement of both measurements. However, the use of 33 kHz frequency is not acceptable for the needs of safe navigation, since depth measurements using this frequency give depths too large by 9 to 18 cm.

Investigations have shown that seismoacoustic profiling can be a useful method for determining the boundaries between bottom deposits in port basins. The best effects were obtained when 10 kHz acoustic waves were used.

References

[1] Bosch, L.A., 1995, *Developments technical fairway management*, 14th World Dredging Congress, Amsterdam.

[2] Bagwell, C., 1998, *Regeneration of harbours for sport & recreation*, Proc. International Conf. On Rehabilitation of Harbour Areas. AIPCN-PIANC, Lisbon.

[3] Conti, M., 1998, *Regeneration of harbour areas for sport and pleasure navigation use. Technical and Environmental factors*. Proc. International Conf. On Rehabilitation of Harbour Areas. AIPCN-PIANC, Lisbon.

[4] Rato, J., Dias L., 1998, *Experiences and results in the creation of new links between port and own*, Proc. International Conf. On Rehabilitation of Harbour Areas. AIPCN-PIANC, Lisbon.