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Field measurements of suspended sediment concentrations in the surf zone

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ABSTRACT Three methods of measuring suspended sand concentrations were selected from existing techniques and field tests were carried out. These include a sand trap, a suction sampler and a radioisotope probe. The problems of calibration were examined. Values and sources of error, integration times for the measurements, ranges of application and accuracy of the above devices were also determined.

Mesure sur le terrain des concentrations de sédiments en suspension dans la zone superficielle

RESUME Les études dans les conditions naturelles ont été réalisées pour trois méthodes de mesure de concentrations des sédiments en suspension. On a effectués l'étalonnage pour les piéges à sable, pour le prélèvement par pompage, et pour le capteur à radioéléments en vue de la mesure de la turbidité. Les études ont permis de déterminer les paramètres techniques et d'évaluer les temps d'intégration des mesures ainsique la précision et les possibilités d'application des capteurs mis au point.

INTRODUCTION

Measurements of sand concentrations agitated into suspension by waves and currents are necessary to evaluate the intensity of sediment transport in the surf zone. The hydrodynamic conditions in that zone are highly complex and are, moreover, nonstationary in both time and space. The measured concentrations of suspended sediment are characterized by variable sediment quality and high local gradients. The ambient current velocities and wave forces are highly significant. Many technical difficulties confront attempts at field measurement and special methods and techniques must be applied. The paper reports the findings of a programme of several years of methodological investigations, carried out by an international group on the Baltic and Black Sea coasts. Detailed results of the measurements can be found in the papers by Antsiferov *et al.* (1976, 1980), and Basiński *et al.* (1980a, b).

SOURCES OF MEASUREMENT ERROR

The following factors may produce errors in measurements and in the interpretation of the results:

(a) distortion of the flow pattern caused by the device and/or the supporting structure;

(b) temporal variations in the salinity, temperature, chemical composition and optical conditions of the sea water;

(c) the chemical composition, grain-size distribution and shape of the sand grains;

(d) the presence of fine organic suspensions, sea weed, pieces of wood and pollutants;

(e) air bubbles in the water;

(f) changes in the reference level due to variable sea level and shifting sea bed;

(g) faults in electronic equipment and control systems, electrical and magnetic disturbances, and the random character of radioactive decay;

(h) insufficient calibration of equipment, wrong location and an inadequate number of measuring points, wrong integration times, and incorrect instrument data.

REQUIREMENTS FOR METHODS OF MEASUREMENT

When choosing and developing a measurement technique, one should attempt to eliminate as many sources of error as possible. The errors which cannot be entirely eliminated should be minimized and the values of inherent errors, which cannot be neglected because of their expected high magnitudes, should be defined. Taking this into consideration, equipment for measuring concentrations should fulfil the following requirements:

(a) The device should be of a shape that causes little distortion of the flow pattern, even at flow velocities up to several metres per second. However, the mechanical strength of the device should be sufficient to resist high dynamic loads. The best solution is to locate the measurement point apart from the main body of the device.

(b) The measurement point should be located as far away from the supporting structure as possible. Moreover, the latter should be permeable, tough and stable and its influence should be experimentally determined.

(c) The influence of different physical and chemical properties of the water and sediment should be eliminated through calibration in the field.

(d) The device should be protected against corrosion, and fouling by floating debris.

(e) The device should follow changes of the bed which may take place during successive measurements.

(f) The device should be reliable, simple and cheap in order to withstand repeated and frequent application.

(g) The chosen method should measure concentrations from 10^4 to 10^{-1} mg l^{-1}; the latter value is required by practical considerations.

(h) Different comparative calibration techniques as well as intercalibration between the methods of measurement should be employed.

(i) For accuracy the concentration should be measured at several points in each vertical profile; the lowest point should be as near the bottom as possible (5-10 cm). Over the first 0.5 m above the sea bed, the measuring points should be spaced no further than 5-10 cm apart; above 0.5 m the spacing may be increased.

(j) The integration time of the measurements should be determined experimentally on the basis of the reproducibility of the results.

EXISTING METHODS OF MEASUREMENT

The methods of sediment concentration measurement in common use, are as follows: photoelectric, radioisotopic and conductivity equipment, bathometric methods, for instance instantaneous bathometers, suction samplers and sand traps. Each of the above methods has many variants described in the literature. The principles underlying the methods, their limitations and their advantages have been reviewed by Antsiferov *et al.* (1976). Three of the above methods are considered in this paper.

Sand traps

The construction of the sand traps and their installation are described in Fig. 1; further details are provided by Antsiferov *et al.* (1980). The sand traps were tested in the field as well as in the laboratory. The quantities of sand collected were compared with quantities measured simultaneously by suction samplers. Using the formula

$$Q_i(z) = k_i(z)\ S_i(z)\ F\ T\ |\bar{U}(z)| \qquad (1)$$

where Q_i = weight of captured particles of fraction (i) at a level (z) during time (T); $S_i(z)$ = ambient particle concentration;

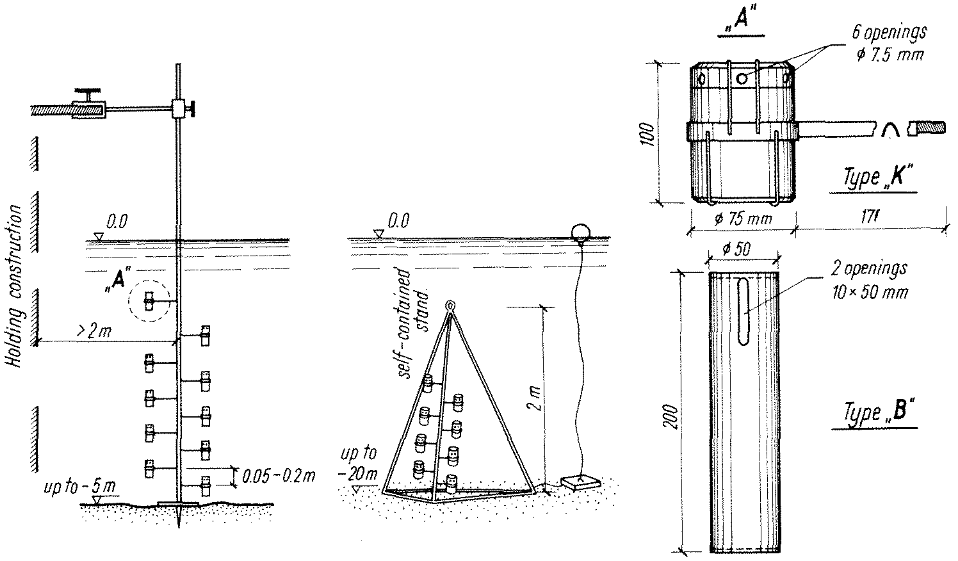

Fig. 1 Sand traps: installation and dimensions.

F = projection of inlet surface; $|\bar{U}(z)|$ = mean value of the horizontal component of orbital velocity. The coefficients of efficiency, k_i, were investigated at different levels, z. The coefficients k_i were shown to depend neither on the value of z nor on the grain size of a particular fraction. Assuming insignificant changes of $|\bar{U}(z)|$ comparable values of $Q_i(z)$ are achieved and relative concentrations can be determined. For measurement of absolute concentration values it is necessary to determine numerical values for $k_i(z)$ as a function of $|\bar{U}(z)|$ which may be achieved by intercalibration with other devices. In order to define the disturbing influence of the supporting structure on the measured values of $Q_i(z)$ the results obtained near the structure were compared with the ones obtained some distance away (10-15 m).

Suction samplers
The sampler construction is shown in Fig. 2, and further details are provided by Basiński *et al.* (1980a). The investigations aimed to define the optimum shape of the suction nozzle, and the flow pattern distortion, as well as to choose the best suction velocity. As a result a discus type suction nozzle was employed. The suction velocity at the discus perimeter is relatively small. Therefore, the water-sediment mixture is sucked from only a thin layer which is of the order of the interstice dimension, and the sand is not drawn from the bottom when the nozzle is very close to it. Nevertheless, the velocity within the interstice is sufficient to collect all grains.

For remote measurements an automated sample collection facility was developed using a series of containers. Moreover,

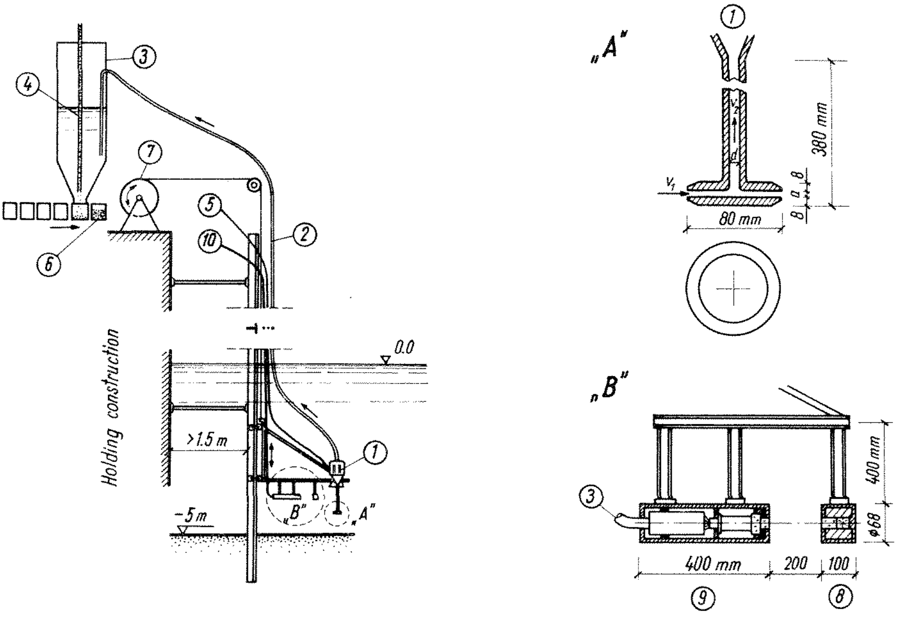

Fig. 2 Suction sampler and radioisotope probe: installation and dimensions. (1) Water pump, (2) hose, (3) water container, (4) water level gauge, (5) and (10) electric cables, (6) collectors, (7) winch, (8) ^{241}Am source, (9) detector.

the integration time for measurements and the reproducibility of results have been analysed.

Radioisotope probe

The design of the probe is shown in Fig. 2, and further details are provided by Basiński *et al.* (1980a). The following formula is employed:

$$\ln(N_o/N) = S\,L\,\rho\,(\mu_{MS}/\rho_W - \mu_{MW}/\rho_S) \qquad (2)$$

in which $\rho = \rho_S\,\rho_W^2/[\rho_S\,\rho_W - (\rho_S-\rho_W)\,S]$ = the volumetric weight of suspended sediment; L = probe base; N_o = amount of gamma quanta passing through a water layer of thickness L; N = amount of gamma quanta passing through a layer of any medium of thickness L; S = concentration of suspended sediment; μ_M = mass coefficient of gamma attenuation by suspended sediment (μ_{MS}), and by water (μ_{MW}); ρ_S = density of sediment; ρ_W = density of water. Since ρ approximates ρ_W for low concentrations, the basic equation for concentration can be approximated by the formula:

$$S \approx \{L\,[\mu_{MS} - \mu_{MW}\,(\rho_W/\rho_S)]\}^{-1}\,\ln(N_o/N) \qquad (3)$$

The investigations attempted to determine the optimum distance L between the radioactive source and the detector, and to define the electrical parameters, the influence of temperature differences and the reproducibility of the results. The probe calibration was carried out in fresh water, in solutions of different concentrations of NaCl, in water with immersed aluminium plates or thin sand layers (Fig. 3(a)) and in a closed circulation of sea water containing controlled amounts of

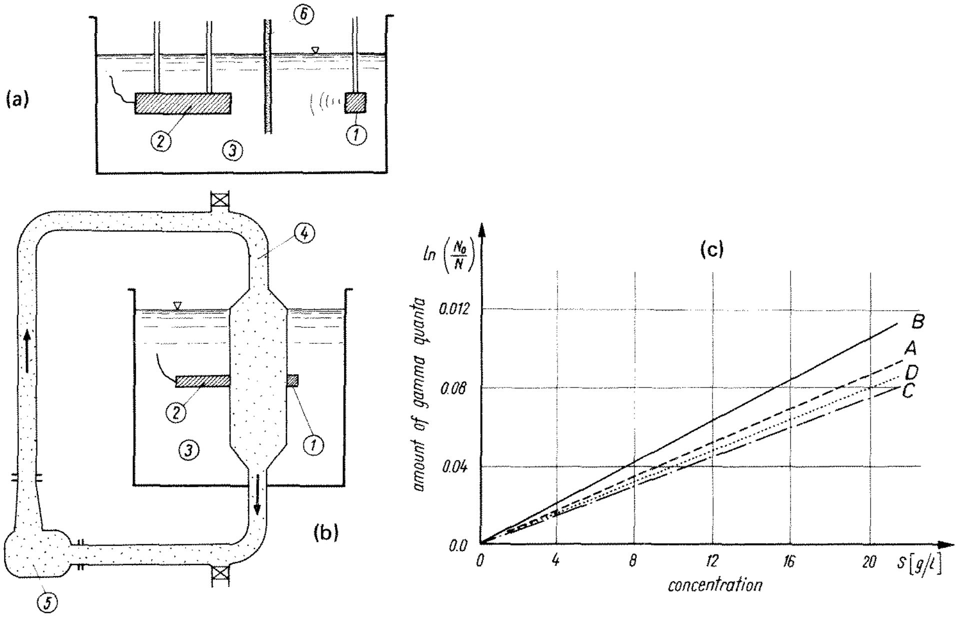

Fig. 3 Radioisotope probe calibration. (a) and (b) Calibration tanks: (1) ^{241}Am source, (2) detector, (3) sea water, (4) sea water-sand mixture, (5) water pump, (6) aluminium plates or sand between plastic plates. (c) Calibration curves for ^{241}Am: A, aluminium plates; B, NaCl solution; C, quartz suspended in water (computed); D, sea water and natural sand mixture.

suspended quartz sand (Fig. 3(b)). The adopted calibration curve is the resultant of all test results shown in Fig. 3(c).

In analysing the origin of inaccuracies in measurement associated with the gamma method, one has to emphasize that the discrete random mode of radiation of radioactive sources involves statistical errors. In order to estimate these errors, tests were conducted with a gamma probe in fresh water and sea water. The number of pulses, N, recorded by the counter for different times of exposure, τ, was found for τ varying from 1 to 1000 s. For each value of τ, tests were repeated at least 10 times. The results indicate that the relative error, ε, in finding N can be determined from the formula

$$\varepsilon = 2\sigma_N/\sqrt{N} = K/\sqrt{J_\tau} \qquad (4)$$

in which $K = 1.94$ (with $\sigma_K = 0.35$) = coefficient corresponding to the error ε with 95% confidence.

Formula (4) shows that statistical errors of the determination of N can be reduced by increasing τ and the activity of the source, J. However, increasing the time of exposure interferes

Table 1 Technical data of the instruments

	Sand traps	Suction sampler	Radioisotope probe
Main dimensions	Fig. 1	Fig. 2	Fig. 2
Calibration	Laboratory and field calibrations to determine relative concentrations	Chosen parameters do not produce any significant deviations	Calibrated in different ways
Distance between measurement points	5-10 cm	1-2 cm	1-2 cm
Minimum distance from the bottom	10-20 cm	2-3 cm	2-3 cm
Real sensivity	A few grams	1 mg l^{-1}	10^3 mg l^{-1}
Sediment measured	Sand	Sand	Sand
Intergration time	Hours	About 100 waves	About 100 waves for mean concentration. 1-100 s for instantaneous concentration (1 s only for high concentrations)
Determination of sediment composition	Possible	Possible	Not possible
Cost	Low	Moderate	High
Application	Relative measurements in any coastal zone conditions	Absolute measurements of mean concentration from piers or platforms	Absolute measurements of instantaneous high concentration from piers or platforms

with the fast response of the probe, while any increase in isotopic activity above 100 mCi is inadmissible for safety reasons and, in addition brings about an increase in size, which is also an unwanted effect. It is obvious that a compromise can be reached by measuring high concentrations with short exposure times and small concentrations with longer times.

Some sources of systematic errors, caused by incompatibility of the physicochemical properties of the measuring environment can be eliminated through calibration under actual measurement conditions.

Comparison of methods

A comparison of the methods employed is presented in Table 1. It seems that all of them may be used in practice but their range of application and the accuracy of obtained results should always be taken into account.

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