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Evaluation of the measurements results of suspended sediments concentration obtained by empirical methods

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The paper presents the results of comparing the data on the concentration of suspended sediments obtained by different measuring systems during the course of experimental studies in a wave channel. Based on the obtained information, a conclusion is made concerning the boundary conditions for the use of specific systems for numerical modeling of dynamic processes in the coastal zone.

Keywords*: suspended sediments, turbidimeter, Transverse Suction System, multichannel pump, ABS Aquascatt-Profiler, Hannover, Large Wave Channel*

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1. Introduction

The coastal zone, as the area of the greatest concentration of human interests, has always played an important role during the history of the World Ocean studying. A deep understanding the role of the coastal zone in the dynamics of the ocean, an understanding of the prospects for development and the need to preserve this most vulnerable part of the ocean, significantly shifted the interest of researchers from the deep-water zone of the ocean to its coastal part. To the most important tasks of geophysical and geoecological forecast movement of disconnected sediments in the coastal zone of the sea include the tasks of the movement beginning of bottom material, formation of the bottom relief, rise of the sediments from the bottom and its intensive movements by the flow. In essence, these tasks are interrelated. That is, with beginning of the bottom material movement, the formation of bottom forms relief becomes possible. The relief development is continuing during suspended sediments are occurrence. In turn, the appearance of the bottom relief will significantly affect the sediment suspension field. This situation forces us to be wary of the analyses results have been performed within the framework of traditional approach, a priori postulates the possibility of studying each process regardless of others. The question of whether results of such an analysis correspond to natural processes in each specific case should be carefully checked.

The complex conditions of ongoing processes limit the possibilities of using the results of theoretical analysis. The problems of sediment dynamics cannot be solved theoretically to the required level of reliable assessment of the quantitative relationships of significantly influencing arguments. To solve them, data from experimental studies should be involved. Diversity of the interaction conditions of various processes in the coastal zone leads to the need of collect an extensive array of experimental data for the various conditions. The most important data in such an array will be observations have been made in extreme situations: in conditions of storms or under the action of intense currents. One of the main tasks of the field experiment was and remains the separation of the influencing factors to arguments of the first and second orders of significance, which, in fact, is the basis for constructing adequate mathematical models. The monographs [1], [2], [3] are devoted to generalizing the results of investigations on problems of sediment dynamics in the coastal zone. Some problems of the sediments dynamics in the coastal zone considered in the monographs [4], [5], [6], [7]. Of course, these works played an important role in the development of ideas about the coastal zone of the sea. However, the accumulated knowledge and experimental data on the interaction of the flow with sediments in extreme situations force to return to the traditional problem and consider it anew, highlighting a number of fundamentally new tasks in it.

From 2006 until 2008, within the framework of the German-Russian scientific and technical cooperation between the "Center for Study of the Coastal Zone of Hanover University and of Braunschweig Technical University" and Shirshov Institute of Oceanology RAS, complex experimental studies were carried out under the program "Modeling of hydro- and lithodynamic processes in the coastal zone". The works carried out in The Large Wave Channel of the Hannover city in three stages. The results of complex researches not considered in a specific work. The article considers only the data of synchronous measurements of the suspended sediments concentration made by different measuring systems for different wave modes. Conclusions have made about the target suitability of each method for solving a specific problem.

2. Materials and Methods

Hard working conditions during storm situations place high demands to the technical means and to the methods of field observations. For many decades, the choice of a reliable method for measuring instantaneous values of the suspended sediments concentration is one of the main tasks, without solving which impossible investigations the process of moving solid material by a water stream. Relevance of this problem has explained by the fact until now is absent strict mathematical description of a two-phase flow movement regularity. The search for empirical dependencies describing the process of sediment transport is impossible without reliable and long-term instrumental measurements of the suspended sediment concentration in automatic or automated mode.

Description and setting of the experiment. As already mentioned, the experiments carried out in The Large Wave Channel (GWK) of the Hannover city. The choice of this channel for a laboratory experiment was due to the fact the GWK wave channel allows to simulate the dynamic processes of the coastal zone without distortion of the scale almost, which is extremely important for mathematical modeling of processes. Under other conditions, it is impossible maintaining simultaneously the similarity of hydrodynamic and lithodynamic processes. The wave channel (fig. 1) has a length of 300 meters, a width of 5 meters, and the depth of the channel from the sides to the bottom – 7 meters. Bottom of the channel is filling with sand. Thickness of the sand filling varies from one edge of the channel to another in the range of 0-5.5 meters. From the deep-water side of the channel a wave generator placed (fig. 2), controlled by a computer.

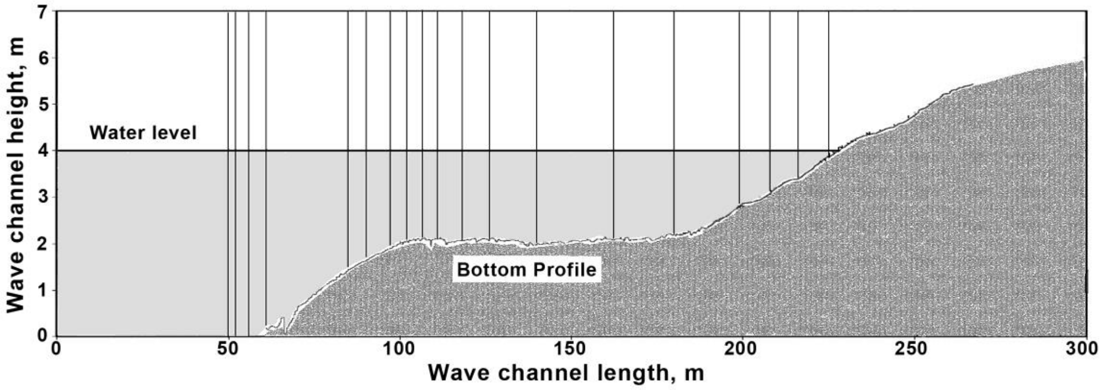

Fig. 1. **Simplified scheme of the GWK wave channel**

Fig. 2. **Above-water part of the wave generator (a); and the view to the wave channel from the side of the wave generator (b)**

The equipment used in the investigations included the following suspended sediment concentration meters: optical turbidimeters (IO RAS) (fig. 3a), a multi-channel pump for water sampling (Transverse Suction System, TSS) (fig. 3b, fig. 3c) and acoustic profilographs (ABS Aquascatt-Profiler) (fig. 3d).

Setting of the experiment. A computer for each specific task of the research was setting the wave mode. For the tests of the meters the concentration of suspended particles in the zones of deformation and destruction of waves, the following scheme of equipment installation have adopted. The turbidimeters sensors were located at the horizons of 12, 23, 32 and 46 cm from the bottom. Water intake gateways of the pump were located at the horizons of 15, 22.5, 29.5 and 39 cm from the bottom. Sensors of the ABS profiler been installed at a distance of 100 cm from the bottom.

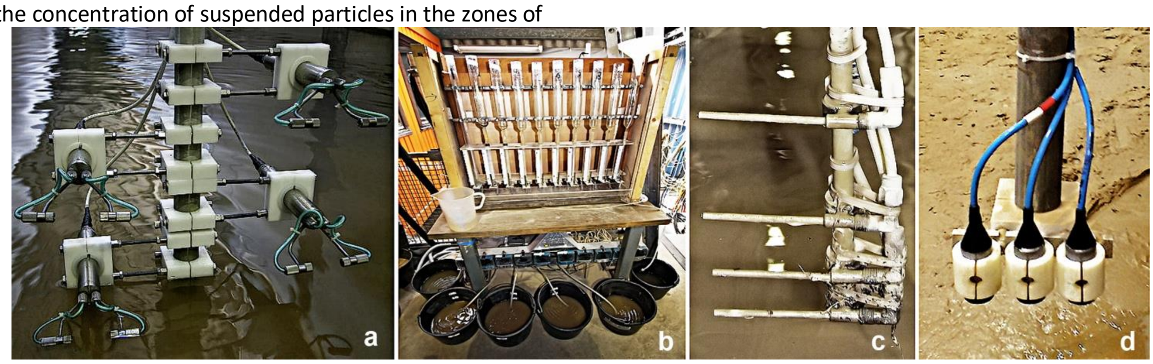

Fig. 3. **Suspended sediment concentration meters: a - turbidimeters; b – multi-channel pump TSS; c – water intake gateways of the pump; d – sensors of the ABS profiler**

Measurements methodology. During the entire experiment, the wave mode was set in accordance with the spectral wave model JONSWAP [8]. The key element of the model is the parameter γ , characterizes the steepness of the wave spectrum at the peak frequency (the peak-enhancement factor). The spectral wave model JONSWAP lays as the basis for further reasoning. The values of parameter γ for different modes of waves vary in the range from 1 to 10. Without going into details (for a general idea), we can say that waves with a large value of γ have high energy at peak frequencies (a wave of the "deep swell" type). The blurred energy spectrum is characteristic of wave processes with a small value of γ (poorly developed wind wave). The examples of graphs of the wave's energy spectra for different values of γ have given in [9, p. 115]. During the experiment, in addition to the parameter γ , generated wave height ($H_{1/3}$) and period of the wave process (T_p) were setting to the program controlling the wave generator.

Duration of the measuring test for each wave mode was 45 minutes. Data from turbidimeters entered into computer at a frequency of 40 Hz. Sampling using pumps have carried out in a 20-minute interval for each test. The profile of distribution the concentration of suspended particles vertically was recording from the ABS meter to computer with a frequency of 1 Hz.

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A detailed description of complex studies under the program "Modeling of hydro- and lithodynamic processes in the coastal zone" given in [10].

3. Results

At the first stage of experiment, testimonies of the turbidimeters and the pump were comparing. For this purpose, a twenty-minute interval was selecting from each measuring test, during which samples were taking using a multi-channel pump. Data from turbidimeters were averaging over the selected period of readings comparison. Comparison of measurement results by the pump and turbidimeters were performing for wave modes with 30% of wave height sufficiency: $H_{1/3}$ = 0.8 m, $H_{1/3}$ = 1.0 m, $H_{1/3}$ = 1.2 m. Period of the wave processes was constant, T_p = 5 s. For each wave mode, 10 tests were conducting with different values of γ parameter. The tests results are presenting graphically in fig. 4.

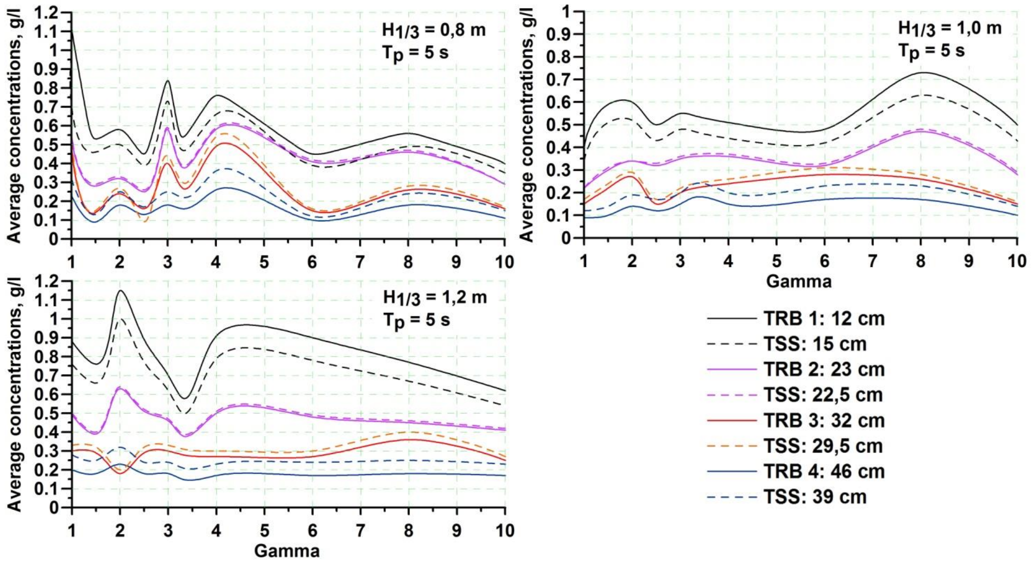

Fig. 4. **Graphs of comparison suspended sediment concentration values according to the readings of turbidimeters and pump for different wave modes**

From the graphs of fig. 4 is seen the data of the pump channels differ little from the readings of turbidimeters. A small difference at the horizons of 46, 32 and 12 cm is due to the fact water intake gateways of the pump been shifted slightly from the level of turbidimeters sensors. It is characteristic if water intake gateway of the pump shifted vertically towards the water surface, the pump readings differ to a smaller direction (horizon 12 cm), and vice versa, if a water intake gateway horizon is shifted closer to the bottom, the pump testimony differ in a larger direction (horizons 46 and 32 cm). When the horizons coincide, the curves of variations of suspended sediments concentration is coinciding, practically, for all wave modes in the entire range of the γ parameter (horizon 23 cm). Illustrations show this regularity is preserving for all of carried out measurements modes.

The next stage of experiment was comparing the testimonies of turbidimeters, pump and ABS acoustic profiler. Comparisons have carried out for two wave modes: $H_{1/3}$ = 0.7 m, T_p = 4.5 s and $H_{1/3}$ = 1.2 m, T_p = 6.5 s. γ parameter remained constant and was equal to 3.

The testimonies were fixing during a time interval of 20 minutes. The horizons of sampling by the pump, measurements by turbidimeters and the installation location of the ABS profiler remained the same as in previous tests. Fig. 5 shows graphs of fluctuations the suspended sediments concentration at four horizons according to testimonies of all measuring systems. On the graphs, X-axis reflects the time interval in seconds, Y-axis – the concentration of suspended sediments in grams per liter. The pump data (blue lines) represent the average values of suspended sediment concentration for the measurement interval. The turbidimeters data (black lines) is a continuous series of measurements of the suspended sediment concentration with a frequency of 40 Hz. Note concerning ABS profiler. Suspension concentrations for each comparison horizon have calculated from a measured profile with a frequency of 1 Hz. Results of calculations have presented on the graphs as the red lines.

4. Discussion

On the methods for measuring of suspended sediments concentration.

Weight method. Sampling using pumps of different designs has used for a long time. The method is time-tested and gives correct information about the average value of the suspension concentration for a certain (sometimes quite long) time interval. The main disadvantages of the method include the duration of the data acquisition process and the lack of the possibility of fine high-frequency measurements. To main disadvantages of method, include the duration of data acquisition process and lack of possibility of fine high-frequency measurements.

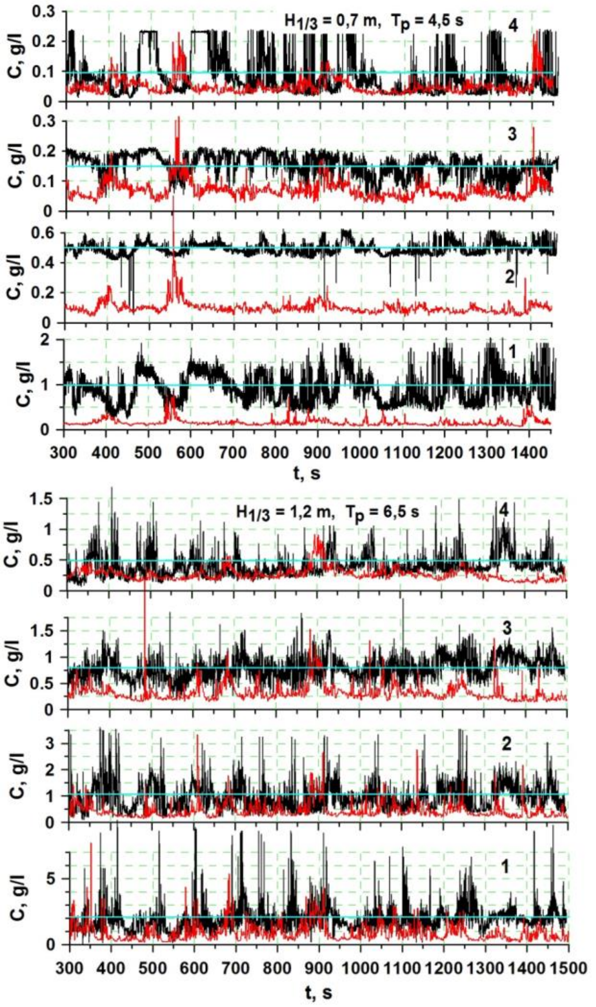

Fig. 5. **Graphs of fluctuations the suspended sediment concentration at the horizons 12 (1), 23 (2), 32 (3) and 46 (4) cm according to data of ABS (----), turbidimeters (----) and TSS pump (----). The time interval is 20 minutes**

Acoustic method.

The method based on dependence of amplitude of a diffusely scattered focused ultrasonic signal of high frequency (up to 5 MHz) on particles suspended in the water column.

The algorithm of signal processing is quite complex and cumbersome. It is a numerical model correct operation has preserving with a certain degree of probability for very narrow boundary conditions [11]. Practice of operating this class equipment has shown their sensitivity to the size and shapes of suspended particles. However, in case of simultaneous use several ultrasound sources with different frequencies of emitted signal, the measurement accuracy increases. ABS device is using for field investigations widely. It is the reason it chosen for intercalibration.

Optical methods.

The methods have based on dependence of attenuation (absorption and scattering) of the light flux by sediment particles suspended in water. During passing through a dispersed system containing solid suspended particles in a liquid, the light beam is scattered and absorbed.

In accordance this, there are two main methods for determining of the suspended material concentration: measuring attenuation of light radiation flux due to suspended particles (turbidimetry); measuring the light energy scattered by particles at angles other than zero with respect to direction of incident light (nephelometry).

Severe dependence of nephelometers calibration characteristics on the scattering angles, as well as on the size and shape of suspended particles, leads to large measurement errors when studying irregular processes in the fracture zone [12]. Usually, for this reason, they have used to measure small concentrations of homogeneous particles at relatively large depths.

However, turbidimetric method for determining of the suspended sediments concentration is not without drawbacks. Testimonies implementing this method devices depending on the temperature instability of electronics components, as well as on the instability of characteristics the light source and photo detector due to aging. How these problems been solved is described in [9]. Here, the theory of turbidimetry and a turbidimeter design has presented in detail. A described model of turbidimeter has developed in Shirshov Institute of Oceanology RAS (Southern Branch). A patent for an invention has obtained for it [12].

Let back to the result of measurement. They have showed (fig. 4, fig. 5), for all of wave modes and measurement horizons, data from TSS meters with high accuracy coincided with the data of turbidimeters averaged over the period of measurements by the pump. Testimonies of ABS profilograph (fig. 5) have lay far from the values obtained by the previous meters mostly.

5. Conclusion

Based on the results obtained, is concluded the data of ABS meters is possible to use for numerical modeling, but only in frame with rigid boundary conditions. In general, the method applicable to solving problems of automatic (automated) data processing, since data on concentrations is available in electronic form. Main disadvantage of method is inability to carry out measurements in areas of actively occurring processes, in particular, in zones of irregular wave's destruction.

The calculations showed in a particular experiment, results of full-scale measurements by turbidimetry, compared with the weight method, gave a discrepancy of no more than 15%. At the same time, high speed of measurements, possibility of express studies of mortars with a high concentration of suspensions, solution problems of automatic data collection and processing make investigations of suspended sediments transport dynamics by the turbidimetric method a priority. In addition, principle of organization the measurements by turbidimetry assumes obtaining an economic effect during field studies.

Turbidimeters have proven themselves on the good side. At the end of experiment, Germany colleagues noted turbidimeters allow for high-quality measurements of suspended sediment concentrations instantaneous values in zone of wave destruction.

Investigations is conducting on the topic No. 0128-2021-0013 "Marine natural systems of the Black and Azov Seas: evolution and modern dynamics of hydrophysical, hydrochemical, biological, coastal and lithodynamic processes".

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