CHAPTER 158

MEASUREMENT OF PARAMETERS, DIRECTION AND RATE OF BEDFORM MIGRATION

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Abstract

Special sensor was developed in the Southern Branch of of the P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences Oceanology Institute, able to register variations of sediment layer thickness in any point of interest on reservoir, sea, channel or river bottom under any hydrodynamic conditions.

Uninterrupted information on geometry, rate and direction of migration of bedforms (ripples, ridges, dunes, bars) in the chosen point of underwater slope can be obtained in the following manner. Three or more sensors are placed by a diver on bottom in a horizontal plane in apieces of equilateral triangle on metal girder. The construction is put deeper into ground to 20-25 cm. Distance between sensors and their spatial orientation are set beforehand. Height and "period" of sand bedforms are found from time variations of sediment layer thickness above any of the sensors. Rate and directions of their migration are calculated by time of bedform crest transit above sensors. Sand wave length is calculated from its "period" and migration rate. A series of laboratory and field experiments has been performed for the purpose of clearing up a sensor working capacity, calibrating and work methods.

Introduction

Migration of sand microforms caused by surface waves, wave currents or channel flows plays an important role in cross-shore, longshore and channel sediment transport. This component of overall sediment transport has not been studied, as reliable instruments for continuous measurement of bedform geometry are still lacking.

Geometry parameters of bedforms are usually measured by divers (Manual...,1975; Kos'yan, 1983; 1987; Miller, Komar, 1980; Dingler, 1974). The diver descends to bottom in calm or slightly wavy weather and while moving along a set route, measures bedform parameters and estimates their shape and spatial orientation in the certain points.

spatial orientation in the certain points. Observation of bedform dynamics by divers has certain disadvantages: information is interrupted, as measurements during storm are not possible; data on rate and direction of

The Southern Branch of the P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences. Gelendzhik-7, 353470 RUSSIA bedform migration can not be obtained; diving works are laborious and expensive.

Method of repeat photography of the same bottom portion from a fixed point (Gizejewski et al., 1982) is used more rarely. Under storm observation of bottom sand layer dynamics seems possible only by measurements taken from rigid trestle bridges, piers and tramways. In other cases the data reflect only post-storm bottom variations.

Uninterrupted information on geometry, rate and direction of migration of bedforms (ripples, ridges, dunes, bars) in the chosen point of underwater slope can be obtained with the use of special sensors.

Such sensor was developed in the Southern Branch of the P.P.Shirshov Institute of Oceanology (Kos'yan, Podymov, 1993; 1994), able to register variations of sediment layer thickness in any point of interest on reservoir, sea, channel or river bottom under any hydrodynamic conditions.

General description

The sensor (we named it sand level gauge) is destined for the investigation of physical aspects of solid particle movement near the bottom, specifically for measuring velocity of formation and shift of bottom accumulative forms, when studying the dynamics of sea sediments on the shelf and the engineer research for the creation of hydrotechnical constructions, etc.

It is an electron-mechanic device for the determination of instantaneous value of the bottom sediment thickness in a selected point. A method of fixation of sediment pressure on the outer metal diaphragm of the gauge, caused by above sediment thickness variations, is realized in this device. Its technical characteristics are in the table 1.

Table 1. Sea level gauge technical characteristics.

-	diameter of a sensible weight accounting membran	ne 0.1 m
	maximum measured weight	5 kg
-	sensibility	0.0002 m
-	change of initial value of output signal, when temperature changes in operating range non-linearity of the output signal according to	<± 0.1%/10°C
	absolute value	<0.7%
-	time constant	<0.1 sec.
	maximum sediment thickness above the sensor	
	during measuring (depends on "arch" effect)	0.25 m
-	maximum admissible shift of the membrane	
	during measuring	0.0003 m
-	supply voltage	±15 V
-	utilized current (without current load)	<0.0005 A
-	utilized current (when output signal is	
	the maximum one)	<0.0025 A
	output signal	0.02 Å
-	range of operating temperature	+1°C ÷ +80°C

The structural scheme of the sand level gauge (Fig.1) includes tensoresistive bridge (1), electronic module of signal formation (2) and electronic module of current formation (3).

Tensoresistive bridge represents four tiny semiconducting tensoresistors, which are placed on a single sapphire backing. Tensobridge is constructed in such a way, that a change of environment temperature is equally inherited to every addition computer access of resistors tensoresistor. In according to their parameter identity let to minimize an error connected with the bridge out-of-balance caused by environment temperature change. Electronic module of signal formation fulfills the stabilization of voltage, which feeds the tensometric bridge, and chooses a out-of-balance signal with the help of circuits of differential amplification. Electronic module of current formation passes the out-of-balance signal to the point of data storage and processing.



Fig. 1. The structural scheme of the sand level gauge.

The device is made as a cylindrical casing, inside of it a manometric unit and dynamometer connected kinematically are placed, and a compensating load-bearing element as well, which effects upon the manometer.

The sand level gauge is used in the following manner. One sensor or a group of sensors are deepened into bottom sediments at the depth of 15-20 cm in the selected point of the shelf. The ground surface above the sensor is flattened. The pressure of sediment cover recorded at the moment of installation is assumed as an initial one.

Shift of accumulative bottom forms (ripples, ridges, dunes) through any point of the bottom causes a periodic change of the sediment mass in this point. When a wave crest is passing, the pressure on the external membrane increases, changing the pressure distribution in and provokes the out-of-balance of the bridge system, which is formed by tensoresistors. When a wave trough is passing, the same effects occur, but the sign of out-of-balance becomes a contrary one. Periodic changes of the water static pressure caused by waves or tide cycles are not displayed in the sensor reading as far as they are completely compensated.

Finally, the gauge secures continuous high-grade measuring of the bottom sediment thickness in a wide range of changing static pressure. Thus, a quantitative information about accumulative bottom form movement can be obtained. And then a velocity of its movement under any hydrodynamic conditions can be calculated. An important feature of the gauge is the isolation of dynamometric assembly from external membrane (Fig.2), that makes easier the compensation of the parameters of the sensor temperature error. The appearance of the sand level gauge is given in Fig.3.



Fig. 2. The cross-section of the sand level gauge construction.



Fig. 3. The appearance of the sand level gauge.

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Communication and data playback

The sand level gauge is connected with the point of the data storage and processing by 4-core cable. Supply voltage $\pm 15V$ and a midpoint are transmitted by 3 cable lines. A separate line brings an information signal as a current, which depends on the bottom sediment thickness. An electronic module of current formation is made as a selftuning current loop with negative feedback, parameters of which do not depend within certain limits on the cable length and resistance. Analog information into binary code with the help of signal is converted dodecadischarge analog-to-digital converter of successive approximation. Output signal of the sand level gauge converted into binary code is being recorded on magnetic carrier of the computer with necessary discreteness.

For the purpose of clearing up a sand level gauge working capacity, calibrating and work methods a series of laboratory and field experiments has been performed.

The laboratory experiment

The main task of the laboratory experiment is to determine the dependence of sand pressure poured on the sensor under the water on the thickness of sand cover and to assess the influence of different kinds of sand upon the "arch" effect.

Electronic units have not been used in order to eliminate their influence on the transmissing parameters of the sensor. A stable supply voltage feeded directly the tensometric bridge. Out-of-balance voltage was recorded by digital voltmeter.



Fig. 4. Grain-size distribution curves for beach and bank kinds of sand, which were used for calibration.

Two kinds of natural sands were used in the experiment. Below they are marked as beach sand and bank sand. According to the data of mineralogical analysis 90% of beach sand are quartz and feldspar with density (ρ_s) of 2.65 g/cm³. A mineralogical analysis of the bank sand has not been done but this type of sand contained a considerably large amount of clay. The assessment of the particle form has not been done. Curves of the particle distribution according to their size (ϕ =-log₂ d), d is a particle diameter) for both kinds of sand are given in Fig.4. Their mean diameter (d mean) is given in the same figure.

The calibrating of the sand level gauge was performed in the tank, which volume was 50 l and the height - 470 mm. The sensor was placed on the bottom of the tank, and then a portion of sand was added. At first the thickness of sand layer covering the membrane of the sensor was 20 mm. The sand layer thickness was recorded continuously. Out-of-balance signal of the tensobridge was fixed by digital voltmeter for every portion of sand. The tank was vibrated after every sand supplement. Then, the vibration was stopped, and 5 minutes later, the thickness of the sand layer above the sensor and a value of analog out-of-balance signal were measured. In the course of calibration simultaneously with sand a small amount of water was added into the tank. The calibration was done firstly for beach sand and then for bank sand. Measuring was stopped, when the tank was brimful with sand.

The check of temperature stability of the sensor work was carried out in this experiment too. Measuring in water without sand has shown that output signal of the sensor remains to be stable one with an error 0.1%, when water temperature changes from 10° to 30° C.

The check of water static pressure on the value of the out-of-balance signal was performed in another experiment. For this purpose the sensor was being slowly lowered from the trestle-bridge to the depth of 5 m. Out-of-balance signal of the tensobridge did not change.

tensobridge did not change. The results of the sensor calibrating for beach and bank sands are given in Fig.5. As it is seen in diagrams, a good coincidence for different kinds of sand and a high linearity of the characteristics of out-of-balance signal U on the sand layer thickness D above the sensor can be observed only when the sand layer thickness is not more than 220 mm. When the sand layer is more thick, the linearity of the dependence is true only for beach sand. Diagram U(D) for bank sand becomes distorted and its slope. The character of the change of the curve slope points to the reduction of the sand layer thickness influence on the pressure given to sensor. Probably it can be explained by the fact that clay, present in sand, binds sand particles and forms interstitial layers of a high strength. Those layers prevent the pressure to pass from the upper layers to the lower ones. We named as an "arch" effect the phenomenon of distortion of pressure. It is evident, that any loose sediments have an "arch" effect. But the value of layer thickness, from which it begins to display, is a characteristic peculiarity of every definite kind of sediments.

The analysis of the laboratory experiment data shows that, when laboratory calibration data are used for the processing of field measurements, the depth of the sensor immersion into sediments must not exceed 220 mm. But it does not exclude the possibility of the sensor use in the conditions different from laboratory ones. Only the calibrating *in situ* for every kind of sediment and conditions is necessary.



Fig. 5. Calibration curves for different kinds of sand.

Laboratory test of the sand level gauge was carried out in a wave flume. This flume was 61m length, 0.8m in width and about 0.7m height (Kos'yan, Onishchenko, Philippov, 1988).

Test consisted in the comparison of bed form height H with D, measured with the help of the sensor. For this purpose the sand level gauge was buried into sand at the depth of 15 cm in immediate proximity to a glass wall of the flume in such a way that an observer can define exactly the bed form position relative to the sensor. While changing the wave producer period of oscillation during 1-2 s we managed to create sand ripples 6 cm high and to move them along the longitudinal axis of the flume. Fig.6a. shows the measuring data of two ripples which have passed just above the sensor during the laboratory experiment.

Full-scale experiment

Field test of the sand level gauge was carried out in the course of international experiments on the Shkorpilovtsy (Bulgaria) testing-ground.

Field test consisted in the recording of the change of bed form height during a storm and in comparison of the sand level gauge reading with the data obtained by divers. The sensor was buried into bottom sediments at the depth of 15 cm in the point



Fig. 6. The results of the change of sediment layer thickness. a - laboratory study, b - field study: 1 -sediment level above the sensor before the storm; 2 - change of bottom relief, measured with the help of the sensor; 3 - change of bottom relief (H) observed visually.

where the sea was 4 m deep. Recording equipment was installed on the trestle and it was connected with the sensor by means of shielded cable. There was obtained uninterrupted three day recording of the change of sand layer thickness above the sensor, and at the same time six control measurements of bed form height were made by divers. The comparison of the sand level gauge reading with the data obtained by divers has shown that the results conform within the accuracy of diver measuring (1-2 cm).

Fig.6b. shows a nature of the change of bottom level at the depth of 4 m during 24 hours in the phase of the storm stabilization. Underwater visual observation confirmed the reliability of instrumental information about little known picture of bed forms near the wave breaking zone. Large sand waves, 14-16 cm high, are covered by ripples, which height ranges from 1 to 4 cm. And the largest ripples are in the troughs of sand waves.

The most intensively sand level gauges were used in joint with the Low Sacsonian Coastal Research Center field investigations in Germany in Autumn, 1994, when complex lithodynamic study in the coastal zone of the Norderney island was done.

Synchronous fluctuations of orbital velocity, suspended sediment concentration and risings of free surface were studied. While measuring it was very important to fix continuously the distance between sensors and eroded bottom. For this purpose under the equipment we buried sensor into sand. It gave us a chance to find sought distance in any moment of measuring. Control measurements of maximum bottom relief deformation during the whole period of observation were done with the help of metal pin with mobile plate. We measured the length of pin from its top to the bottom and then determined changes of bottom level during the time period between measurements. When sand near the pin was washed out, the plate, put on it, dropped.



Fig. 7. The comparison of measuring of an active layer thickness with the help of sand level gauge and metal mobile plate.

When bottom erosion changed into aggradation, the washer was covered with sediments and showed the most low level of the bottom during the period between measurements.

A comparison of the data obtained by measuring of the

bottom form deformation by means of sand level gauge and by classic method, i.e. by measuring with the help of metal pins and plates, was made in the course of lithodynamic investigations. The results of one such a comparison are given in Fig.7 (measuring was done during 12 hours). The technique of obtaining these results was the following: during the low tide, when a place, where the sensor has been installed, was drained, a metal pin was hammered into sand at the distance of 1 m from the sensor. A heavy flat mobile plate with a hole in its center was put on this pin. The plate dropped along the pin and lied down the sand surface. Necessary measurements were made after a tide cycle, when the place of the pin positioning was drained again. It was supposed that if a deformation of the bottom profile would take place, then the thickness of an active layer in this place could be determined with the help of the mobile plate. If the sediment accumulation was the first stage of the bottom deformation, which was replaced by erosion and then by accumulation again, the quantitative information about the first accumulation was lost. Full line in Fig.7 shows the bottom profile in the measuring point, obtained with the help of the sand level gauge. Here, t_1 is the time of metal plate placing on sand; t_2 is the time of measuring of the depth of the plate sinking.

Introduced notations have the following sense:

 $\Delta D_{\rm S} = D_{\rm S}(t_1) - Dmin$ is the thickness of an active layer for the time period $t_1 - t_2$ according to sensor data. The initial process of accumulation has not taken into account as far as it is not fixed by plate. As it is seen, $\Delta D_{\rm S} = 8.5$ cm.

is not fixed by plate. As it is seen, $\Delta D_{\rm s}$ =8.5 cm. $\Delta D_{\rm p}$ is the thickness of an active layer, obtained with the help of the plate. According to the results of measuring $\Delta D_{\rm p}$ =8.0 cm.

As it is seen from the comparison, the difference is not more than 0.5cm.

While measuring a bench mark pin was used for the absolute tie of the surface send level to the environment. The sensor position was fixed not by the depth of its burying, but by the distance from the top of the bench mark pin. In such a manner the the recording of sand surface relative to the top of the bench mark pin was done.

As a typical example Fig.8 shows a fragment of 7-day recording of sand surface level relative to the top of the bench mark pin. This fragment was obtained by measuring with sand level gauge (interrupted line). Gaps in the line correspond to low tide, when the place of the sensor positioning was drained, and measurements were not done.

In this figure, level of sand surface measured by a rule from the top of the shelf mark pin in the moments of complete discharge in the point of the sensor installation is marked by small circles. Vertical lines show the thickness of active layer during the period of two measurements, obtained with the help of mobile plates.

Discussion

The results of the laboratory calibrations and full-scale tests testify to the sand level gauge fitness for the investigation of the physical aspects of solid particle movement in the near bottom water layer, especially for the measuring of

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the rate of accumulative form formation and shift, when studying the dynamics of sea sediments on the shelf.

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The above sensors can be used for routine monitoring of raceway, harbor and river channel silting, and for continuous observation on dynamics of bedforms (ripples, ridges, dunes, bars) under any hydrodynamic conditions in zones practically inaccessible for other observation techniques.

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