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Article

A case study: Development of water wave measurement systems under the self-made principle

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Abstract

The paper describes the development and modernization of sensor systems for the assessment of wave characteristics in the coastal zone, the measuring equipment, and data transmission system. Step by step improvements of the wave platform are described. The test results were analyzed, which were carried out during research expeditions of the LMNAD (Laboratory of Modeling of Natural and Anthropogenic Disasters) to Sakhalin Island within the framework of the study of the Okhotsk Sea coastal zone near Cape Svobodny in 2017-2019. The paper mentions the operations of the sensor-recorder of shallow water waves at each stage of the development. The conceptual design of the next generation wave platform is briefly presented.

Key words: coastal zone, monitoring, wave characteristics, data collection

1. Introduction

There have been a variety of methods for measuring sea waves developed and used. Among these the more popular or frequently used methods are:

1. Pressure gages
2. Step gages (resistance type
3. Step gages (relay-activated type)
4. Wire gages (resistance type)
5. Wire gages (capacitance type)
6. Altimeter
7. Accelerometer buoy
8. Ultrasonic (above water type)
9. Ultrasonic (submerged type)

The authors had examined which methods would be appropriate to our self-made observation system for waves in shallow water, taking account of natural conditions of wave measurement sites, costs and availability of the basic devices and elements, necessary for the system.

As to the natural conditions of wave observation sites, the coastal region of south-eastern Sakhalin Island in the Sea of Okhotsk has beach with gently declining slope (Fig. 1). The sea is covered by sea ice in winter while in other seasons sea waves prevail. Recently the activities of energy industries and fisheries in the regions are increasing, information of natural conditions such as wind, sea waves, sea ice, and their databases have been crucial for such activities. The existence of sea ice, particularly pack ice, in winter hardly allows us to apply floating type methods, except for expensive solidly built buoys.

After try and error experiences, in 2017, the authors had firstly adopted the wire gage of capacitance type mounted on the container of the platform. As the water moves up and down, total wire capacitance changes. On the prototype platform, single wire gage was quipped. If the platform has a slightly bigger surface enough to mount two wire gages vertically a short distance apart, the difference in recording between the two is a measure of water slope.

The recording of capacitance versus time, equivalent to wave-height and tidal motion versus time, is transmitted to a radio receiver onshore.

The authors designed and assembled a prototype platform themselves from parts, and completed a unique platform, equipped with the sensor and other devices, which could creep slowly on the land and the sea bottom to the observation sites offshore, bearing up under the external loads. Since then, the authors have begun to modify the major portions of the platform step by step, to improve the platform movements and to increase its reliability on the cost effectiveness principle (Kurkin and others, Zaytsev and others 2017). Wave measurement tests were carried out with each version of the platform. Each test data was utilized to design its next version.

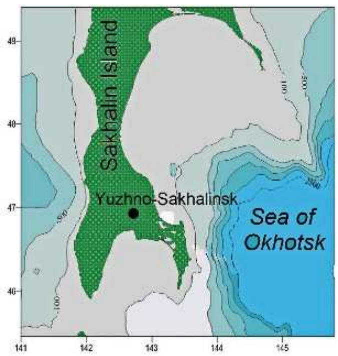

Fig. 1 South-eastern Sakhalin Island and the Sea of Okhotsk

2. Creeping Wave Platform: Prototype

The prototype of Creeping Wave Platform (CWP) was consisted of a main structure, a watertight container of measuring units, a stepping motor, driving wheels, supporting wheel, arms to adjust the posture of the platform, and a wire-sensor. The movement and the posture of the platform was remotely controlled (Kuzin and others, 2018).

The CWP and its chassis are shown in Figs. 2 and 3.

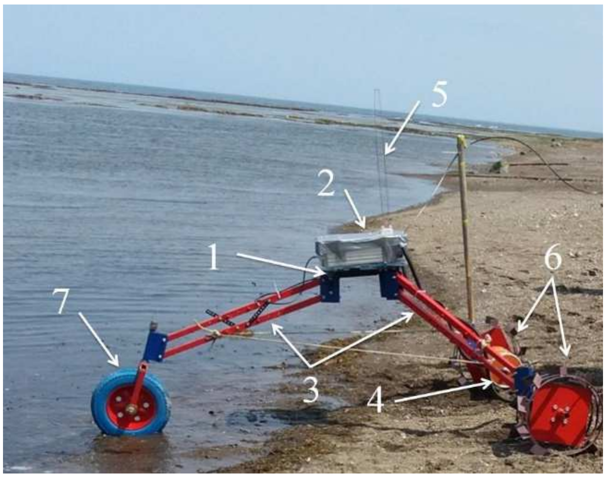

Fig. 2 Creeping Wave Platform
(1) main structure, (2) watertight container,
(3) arms to arms to adjust the posture of CWP,
(4) stepping motor, (5) wire sensor,
(6) driving wheels, (7) supporting wheel.

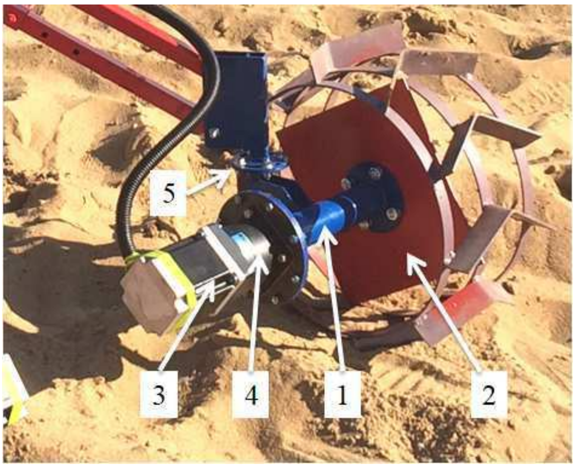

Fig. 3 Chassis of CWP
(1) hub assembly, (2) wheel, (3) stepping motors,
(4) bare gear box, (5) pivoting assembly

Using a small rigid pillar of 60cm long, the wire gage was stretched in a straight line along the pillar. A video camera was installed in the watertight container made of polymethylmethacrylate, which gave a clear window to the camera.

Li-Po battery provided electric power of 48V and 12.5A provided electric power to the platform. This battery and other devices such as stepping motor driver OMD-88 and control unit (minicomputer Raspberry Pi2) were installed in the container. The stepping motors FL86STH118-4208 with rating torque of 8.7Nm drove the wheels of the platform. They could shift into reverse via the planetary gear box PX86 with gear ratio 1:10, for increasing the torque.

A laptop computer with patch cord for management of communication controlled the platform, where. observation data were automatically saved in a storage card.

The arms were composed with steel pipes, which weight was tried to be as light as possible, while the arms held the strength to endure the external forces. The lengths of the arms govern the sufficient strength of the platform and its stability, seaworthiness, and resilience as well. The authors chose the maximum length of the arms of 920mm and the minimum one of 770mm, after computations.

In this case, the overall length of the platform could vary by changing angle at the connected points of the arms from 40 to 120 degree. The angle will be able to vary as accurate as ±1 degree, since the platform should have suitable configuration for stability and movability. The means of adjustability of the angles are crucial for it, at the time when different measuring units need to install in the container.

On the design of the watertight container, the position of its center of gravity was carefully examined and adjusted. When the wave platform creeps on the land and gently declined sea bottom, the position of the center of gravity of the container, as well as the configuration of the arms, is one of the important issues for stable and smooth movement of the wave platform.

The prototype platform was tested at the SCB SAMI FEB RAS “Cape Svobodny” Station site from July 7 to July 9 in 2017.

The test site and overall circumstances of the test are shown in Fig. 4.

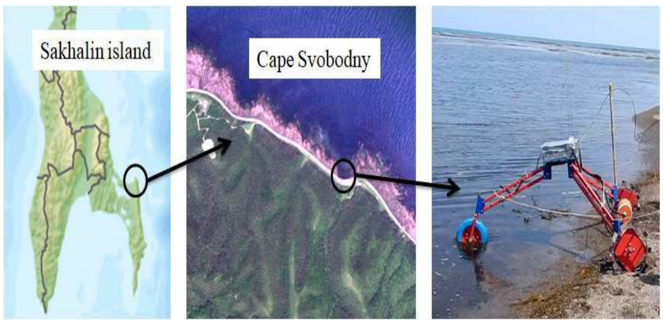

Fig. 4 Test sites in 2017

When the wave platform firstly went into water, an accident happened. It casually moved into a seaweed bed area and its propulsor got entangled with seaweed. By good fortune, the platform could move ahead to the area of 45-50m offshore and it fully submerged in water. The platform stayed there for 40 minutes, for performing observations and recordings, and then moved back ashore.

The authors continued the tests with this prototype platform in July 2017 at different sites around Cape Svobodny of the coast of the Sea of Okhotsk on Sakhalin Island, where the sea is shallow and 2-4m deep in the area several hundred meters away from the shore. Among the test sites, one site case was touched upon. The remotely controlled wave platform was set at the location 50m away from the shore and 2m deep. The measured wave data were remotely transmitted to the data center on shore.

As for the verification of observed data were carried out after the slight modifications made on the prototype, by utilizing a land/submergible mobile robot system (Rodin and others, 2016).

A typical example of data obtained by the wire sensor is shown in Fig. 5.

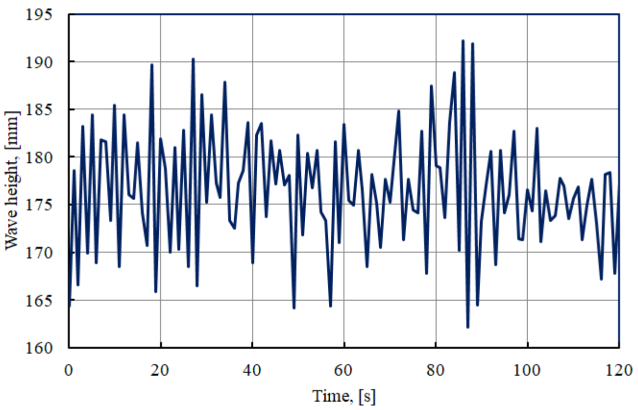

Fig. 5 An example of breaking waves recorded by the wire sensor

3. Towards an autonomous system

The remotely operated wave platform could creep well on slope beaches by stepping motors far from shore, about 100m offshore under remote control. However, accumulating considerable experience, the sensor system was found to need to replace to improve accuracy of measurements, getting rid of the surface tension of the water. In 2018, the wire sensor of capacitance type was replaced by two pressure sensors and an atmospheric pressure sensor was added to the sensor system. The watertight container, in which contains various units for measurements, was redesigned to the one made of thick acryl glass. The new container designed to have the flexibility to exchange measuring and recording units in the container.

The measuring system was polished up: installation of a laptop computer to control and manage every unit and saved data of up to 20Hz sampling frequency.

The new platform, equipped with two hydro-pressure sensors, was able to measure waves in two directions: parallel to the shoreline and at the right angles to it.

The data transmission system fully changed to the wi-fi mode, mounting an 8dB antenna adjacent to an atmospheric pressure sensor, with which an operator was able to move the wave platform into water by remote control.

Trial tests were carried out in Lake Tunaycha, the largest body of fresh water on the island locates 45km south-east of Yuzhno-Sakhalinsk.

The modified wave platform at Lake Tunaycha is shown in Fig. 6.

Fig. 6 The modified wave platform at trial test site, Lake Tunaycha (2018)

4. Further Improvement: Unmovable wave platform

The accumulated experience suggested other modifications of the wave platform. In accordance with expansion of wave measurement sites, accident risk in creeping movements of the wave platform in seaweed bed area increased and it took much time for an operator to set and remove it, even with engineering difficulties.

The authors had given up the movable wave platform reluctantly and decided to set and remove it manually.

Detaching mechanical parts for movement, the wave platform was fully redesigned again. Its major part was a container made of thick acrylic, which was fixed on the welded frame structure.

An atmospheric pressure sensor was fixed on a thin pillar, 3m above the hydro-pressure sensors.

Overall size of the modified unmovable wave platform was reduced to one fifth of the former one.

Transport measure of unmovable wave platform was simple by a boat. Hovercraft might be used for its transport, but it would be rather inconvenient to set up and remove the platform.

The unmovable wave platform is shown in Fig. 7.

Fig. 7 Unmovable wave platform at Cape Svobodny (2019)

Utilizing compact and low power units, the power requirement of the system was relatively low. Recorded data were transmitted by cables and/or via wi-fi mode.

Maximum service life of the unmovable wave platform was 7 days. When the wi-fi mode was used, some additional sealing treatment was required.

The trial test of the total system, hardware and software, of the unmovable wave platform was performed at the coastal zone in Mordvinov Bay, Cape Svobodny in 2019 (Kurkin and others, 2020), and in Gorki Reservoir (near Nizhny Novgorod) as well. Gorki Reservoir is a fresh water reservoir in the River Volga, constructed by the Nizhny Novgorod Hydroelectric Power Station.

5. Further Improvement: Container material

The activities of the wave platforms are both in fresh water and sea water. Considering this chemical/physical conditions of the activities, the container should be much more tolerable to the environment.

The acrylic container is to be replaced by PVC cylinders. The hardware such as battery charge controller, integrated status display, power relay related to reed switch or RFID key will be installed, which confirm the watertightness of the core system, to avoid complex connections of units and drilling unnecessary holes onto the container.

The design concept is shown in Fig. 8

Fig. 8 Concept of the core portion of a future wave platform.

The above-mentioned core portion of a future wave platform will be made by 3D printing.

The atmospheric pressure sensor will be equipped on a float buoy, made by 3D printer. The float buoy will install wi-fi transmitter with an antenna.

The wave recorder on shore will not be interrupted by the actions such as removing the wave platform.

For the moment, its final concept is being elaborated.

6. Conclusion

Step by step developments of wave platforms under the self-made principle has been described in short.

The extremely shallow natural conditions of wave measurement sites and lack of finance support have hampered its rapid development.

The first model had begun with creeping wave platform, which would be considered suitable for the shallow and declined slope beach. However, the existence of seaweed beds stood in the way of development of this type of wave platform. After abandonment of the movable type, the authors replaced the sensors of wave measurements from the wire gauges to the pressure gauges to improve the accuracy in wave record, together with changing the core units. The data transmission system between the wave platform and the data center on shore has gradually been modified up to the present.

The outline of the conceptual design of the next generation wave platform is presented.

As the wave spectrum in shallow water zones has regional differences. The authors do hope the next generation wave platform will provide ample and accurate wave data and will be able to step forward to present the wave data base and propose the reginal wave spectrum soon.

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