Development of A New Ocean Bottom Seismometer (Model IV of Kyoto University)

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Abstract

Seventy percent of the surface of the earth is covered by ocean. It is necessary to observe earthquakes in the sea for the study of solid earth. The group of ocean-bottom seismological observation of Kyoto University has developed ocean bottom seismometers (OBS) of three types over the last several years. In the present study, we present our newly developed OBS which deploys free-fall and pop-up methods. This OBS is equipped with a three-component geophone (Mark Product L-22D) and a digital recorder. The recorder digitizes seismic data by a 16 bit analog-to-digital converter and writes the data on a magneto-optical disk with a capacity of 326 megabytes (MB). The electronic circuit boards are all housed in a 17-inch-diameter glass sphere. Thus, we will be able to obtain seismic data of high quality reading the seismographs from this high dynamic range seismometer installed on the sea bottom. The present OBS has an electrical corrosion mechanism permitting the release of the main OBS unit from its anchor at the sea bottom when it is retrieved. Recording tests on land and popping-up tests in the sea were performed, confirming that the present system is reliable enough to record seismic data under long-time submarine deployment.

1. Introduction

To investigate seismicity and structure in the vicinity of tectonically active areas in the ocean, we need submarine seismic observation in the ocean by Ocean Bottom Seismometers. Such a seismometer must meet severe limitations in size and weight, and in addition is required to be capable of sufficient long recording time and suitable bandwidth and dynamic range. In 1988, a group of ocean-bottom seismological observation of Kyoto University began to develop the OBS. Since then three types of OBS have been developed (Tsutsui et al., 1989; Katao et al., 1993; Katao et al., in preparation). In Model I, an analog recorder called "OM system" (Oike and Matsumura 1985) was used. In Models II and III, digital recorder systems were deployed. Models I and II were equipped with one vertical and two horizontal geophones with a natural pendulum period of 1-s and electronic circuit boards within a 17-inch-diameter glass sphere. These two models are basically identical except for the recorder system. Model III was mounted with a digital recorder that was the same as that of model II, and three servo accelerometers housed in two aluminum cylinders. A higher power supply is needed to operate this system than the previous ones. From the beginning of development of the first model OBS, these three types were all designed to be placed on hard rock on the seafloor by using a submersible vessel, in order to avoid the distortion of seismic waves by soft and thick seafloor sediments (Tsutsui et al., 1989). However, these OBS were too heavy for operating on ship; Model I and II are nearly 100kg, and Model III is 120kg in air. The sensors of the 1-s pendulum period were rather big and heavy for such a small portable OBS. In addition syntactic foam floatation, which was necessary to give enough buoyancy when retrieving an OBS made the OBS even heavier. Models II and III, which employ a digital recorder were designed to record ground motions on erasable-programmable ROM (EPROM), the memories of which are very limited, being 4MB for Model II and 12MB for Model III. Because of the above limitations, the previous OBSs of Kyoto University were unsuitable for observation of natural earthquakes which requires deployment of many OBS at once for aftershock observation. Nevertheless, the geophones of semi-long-period natural frequency mounted in model III are suitable to record longer period seismic waves with a wide bandwidth, and high dynamic range, so that these geophones can make a significant contribution to global seismology.

We have developed a new free-fall and pop-up type of OBS called model IV of Kyoto University (KUOBS-IV). The Free-fall type of OBS is easier to set on the ocean bottom and is more economical than any other type of OBS, for example cable type or anchored buoy type. In this new OBS, a digital recorder capable of obtaining a wide dynamic-range is employed. There is also a set of three component geophones with a natural pendulum period of 0.5-s that makes the OBS smaller and lighter, and gives sufficient space for installing a digital recorder that has enough capacity to record ground motions on magneto-optical disk (MO disk). The purpose of this paper is to present in detail the mechanics and operation of KUOBS-IV.

2. Ocean bottom seismometer system

2.1 General configuration

The new model OBS described in this study is a free-fall and pop-up type OBS, such as has been deployed in most modern OBS [e. g. Nagumo et al., 1982]. A photograph of the complete instrument assembled to the anchor is shown in **Photo. 1**. The specifications of this OBS are given in **Table**.

This OBS is equipped with three orthogonal geophones and a digital recorder with a MO disk drive. The digital recorder has a pre-amplifier and built-in quartz clock. These instruments and a set of batteries are all housed in a 17-inch-diameter glass sphere manufactured by Benthos Inc. This glass sphere is installed in a plastic hard hat. For the retrieval of the OBS, we adopted a release system developed by Kanazawa (1986) that uses an electrical corrosion mechanism that dissolves a thin stainless steel plate which connects the anchor to the plastic hard-hat. After disconnection the OBS floats up to the sea surface. This process is initiated by an acoustic command transmitted from a surface vessel. A transducer is mounted outside the OBS hard-hat to receive the

Table: Specifications of KUOBS-IV

General		
	Non-anchored net buoyancy	10kg (approx.)
	Total weight (in air)	68kg (approx.)
	(in sea water)	42kg (approx.)
Pressure Case		
	Diameter	43.2cm (OD)
		40.4cm (ID)
	Weight	17.7kg in air
	Net buoyancy	25.4kg in sea water
	Material	Low expansion borosilicate
	Manufacture	Benthos Inc.
Anchor		
	Material	Iron
	Weight	33kg
Instrumentation		
Geophone		1 vertical and 2 horizontal
	Type	Marc Product L-22D
	Natural frequency	2Hz
	Coil resistance	2200 ohms
	Sensitivity	6V/kine
	Open circuit dumping	0.46
	Geophone leveling	Mechanical gimbal with 10^5 cS silicon oil
Recorder		
	Type	DTC-6030 (Colombia import & export co., ltd.)
	Type of recording	Digital recording by 16 bits analog-to-digital converter
	Recording media	Magneto-Optical disk (one side)
	Power requirement	5W (usual operation)
		60W (operating MO drive)
Amplifier		
	Channel	4
	Gain	16 position from 0 dB to 60 dB
	input impedance	1M ohms
Clock		
	Precision	less than 5×10^{-7}
Batteries		
	Type	lithium cell
	Number	60
Acoustic release system		
Electronics releasing side		
	Method	Electrical corrosion
	Corrosion part	0.5-mm-thick stainless board
	Corrosion time	less than 10 minutes
Side with mechanical disconnecting		
	Method	Passing through the ring
Searching support system		
	Flasher	FL-6000 (Taiyo Musen co., ltd.)
	Radio beacon	TB-309A (Taiyo Musen co., ltd.)

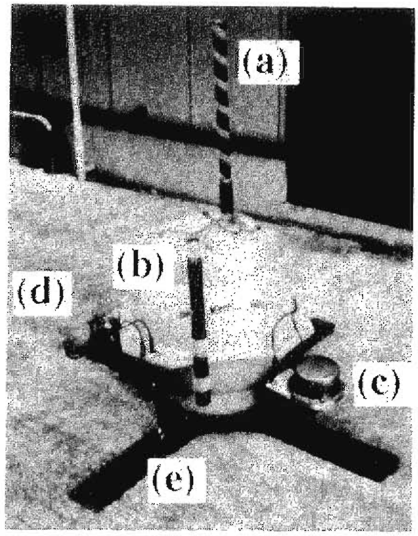


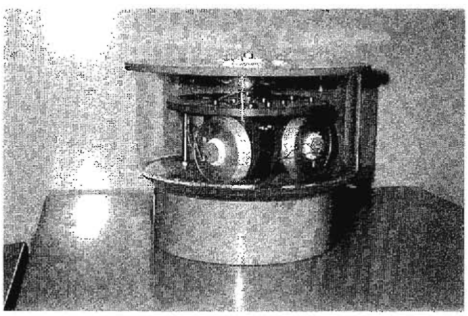
Photo. 1. A photograph of newly developed OBS (model IV of Kyoto University). (a) radio beacon, (b) flasher, (c) transducer, (d) transponder pressure vessel, (e) anchor.

acoustic command. This transducer can also be used to measure the distance between the OBS and surface vessel. To facilitate the retrieval of the OBS, a flasher and a radio beacon (made by TAIYO MUSEN co., ltd.) are attached. These instruments send flashing light and radio waves from the floating OBS after its ascent.

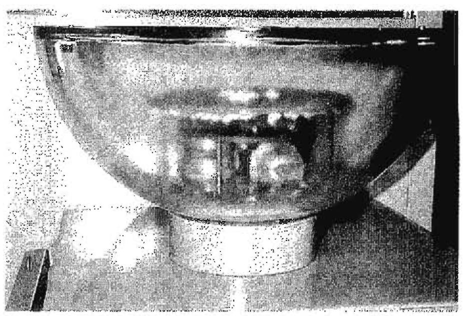
The anchor is made of crossed iron bars. The weight of this anchor is 33kg in air and thus the total weight of the OBS is 68Kg. This is much lighter than the previous models developed by Kyoto University.

2.2 Sensor

Three MarcProducts L-22D geophones are installed in the present OBS. The



(a)



(b)

Photo. 2. (a) Gimbal with two horizontal and one vertical geophone (Marc Product L-22D) is housed in its case. (b) Gimbal mounted on the bottom of a glass hemisphere.

natural pendulum period of the geophone of 0.5-s is shorter than those used in the previous models. Three geophones, one vertical and two horizontal, are orthogonally mounted on mechanical gimbal (**Photo. 2 (a)**). If the OBS lands on the seafloor tilted, this gimbal can maintain the verticality of the geophones within an accuracy of 15°. The gimbal is housed in a plastic case which is set at the bottom of the glass sphere (**Photo. 2 (b)**). High viscosity (10^5 cS) silicon oil was chosen as a damper and is contained in the gimbal case as employed by Kasahara et al. (1979) and Kirk et al. (1982). This silicon oil keeps the gimbal mounted geophones effectively rigidly coupled to the movements of the OBS at periods of seismic waves. Output signals from the geophones are transmitted through terminals on the gimbal case.

2.3 Recorder

A digital recorder (DTC-6030) is used as the data recording system in this OBS (**Photo.** 3). This recorder amplifies the output of the geophones through the pre-amplifier, digitizes the data with a 16-bit analog-to-digital converter, and then stores the digitized data on a single side of the MO disk. The gain of the pre-amplifier can be selected among 16 positions from 0 dB to 60 dB. The sampling frequency of the analog-to-digital converter can be chosen among 1, 2, 4, 5, 10, 20, 25, 50, 100, 200, 400, and 800Hz. The dynamic range of the analog-to-digital converter is 96 dB. Since the pre-amplifier can input 4 channels, one more sensor, e.g. a hydrophone or tilt-meter, can be attached in addition to the three geophones now installed. This recorder contains a built-in quartz clock of high precision within 5×10^{-7} and the time signal is written on the MO disk with digitized geophone signals. Time precision is a very important factor in seismic observation. However we cannot correct the clock of the OBS directory during observations. Fortunately, water temperature is quite stable at ocean bottom, so the OBS clock shifts almost linearly. We can thus correct the OBS clock by linearly interpolating the time shifts which are measured before and after observation.

As for the recording mode, either a trigger or a timer can be selected. In both recor-

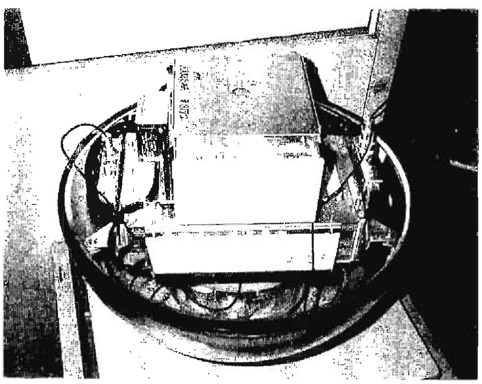
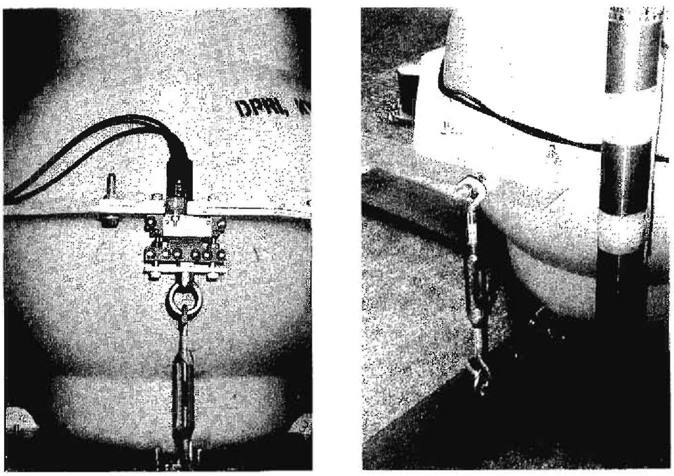


Photo. 3. A photograph of lower glass hemisphere. The recorder (DTC-6030) is mounted above the gimbal case. MO drive is attached on top of the recorder.

ding modes, digitized data are stored on a temporal buffer memory first and then written on the MO disk. This allows the sensors to avoid recording the noises produced by the MO disk drive while writing the data onto the disk. The capacity of a single side of a MO disk is 326MB, so that the data for about 75 hours can be stored on a MO disk from the 3 channel inputs at sampling frequency of 200Hz. This recorder requires 5W electrical power supply in usual operation, and 60W when the MO drive is operated.

2.4 Release system

When this OBS is deployed for observation, it is coupled to the 33kg iron anchor, so that the total weight of this OBS is 68kg in air and 42kg in water. At the end of observation, the OBS needs to release the anchor and float up to the sea surface. Several different kinds of release systems have been designed, such as mechanical release, electrical corrosion, and explosive bolt by timer or acoustic command or some combination of these two systems [e.g. (Kasahara et al., 1979), (Nagumo et al., 1982), (Willoughby et al., 1993)]. The release mechanism used in the present OBS is similar to the OBS developed by Tokai University (Baba, 1988) and is illustrated in **Fig. 1**. The retrieval part of the OBS is connected to the anchor by two connection parts. One is the separation part involving electrical corrosion (**Photo.4 (a)**). This part connects the main unit which is recovered to the surface and the anchor by a 0.5-mm-thick stainless steel plate (Kanazawa 1986). At the time of retrieving the OBS, an acoustic command is transmitted from a surface vessel. The OBS receives this command and starts to apply voltage to be corroded. The stainless steel plate is decomposed within about 10 minutes. Another part connects the two units by a mechanical slip ring (**Photo.4 (b)**). When electrical corrosion is finished and the main unit of the OBS begins to rise, the stay of the retrieval



(a) (b)

Photo. 4. Photographs of release parts. (a)Electrical corrosion part which connects the OBS main body with anchor by 0.5-mm-thick stainless board. (b) Mechanical slip disconnection part. Anchor hooks the stay of OBS main body.

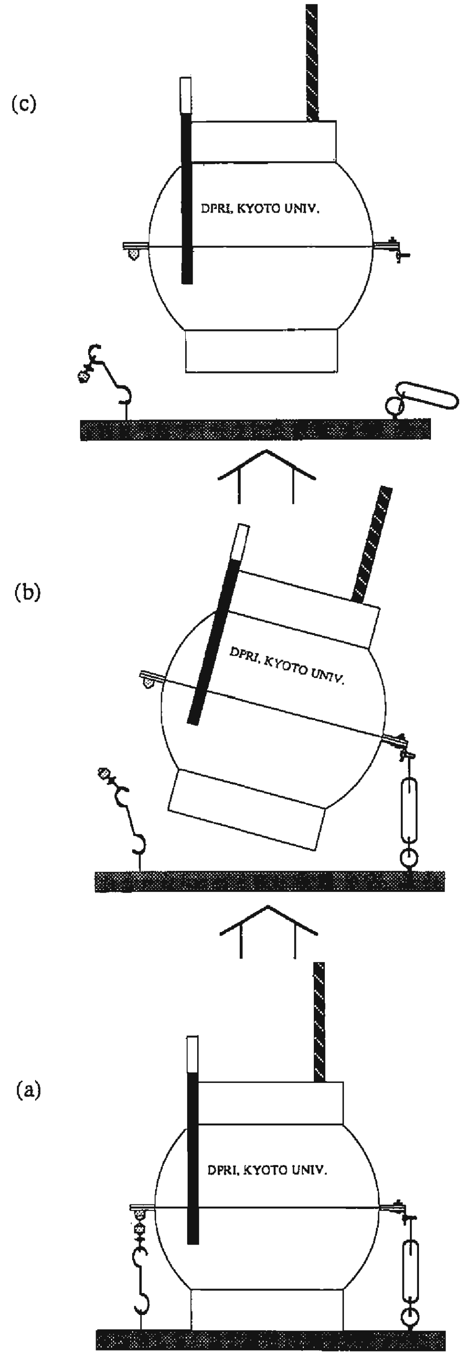


Fig. 1. The retrieving process of this model (modified from Baba, 1988). (a): OBS is in the state of observation at the sea floor. Acoustic release command is transmitted to OBS at the retrieval, upon which OBS starts electrical corrosion to separate anchor. (b): When the electrical corrosion finishes the separation, OBS main body begins to rise. (c): Finally, the stay of the OBS main body passes through the hook of the anchor.

part passes through the hook of anchor. This system is very simple and reliable.

2.5 Support system of OBS searching

It is difficult to find the floating OBS on sea surface without any instrumental aid. A flasher and a radio beacon are therefore mounted to facilitate finding the OBS at the retrieval. The flasher starts to emit light at night and the radio beacon begins to transmit when the OBS comes to the sea surface. The flasher gives location, while the radio beacon gives the direction. Furthermore, we can estimate the distance between the ship and the OBS by transmitting an acoustic command from the ship because the OBS's transducer is designed to be below the sea surface while the OBS is floating. These systems are expected to make the finding of the OBS easy.

2.6 Battery

It is necessary for digital recording to supply more electrical power than for analog recording, demanding batteries with large capacity. In the KUOBS-IV, a set of 60 Lithium cells are used for the recorder and are placed around the gimbal case and beneath the recorder. This kind of battery has a large electric capacity, so that it is suitable for long-time observation. On seismic observation, time precision is a very important factor. At the deployment of this OBS, the clock has to operate throughout the observation period and needs a power supply unit independent of the recorder's battery unit. The exterior instruments such as the transducer release system, flasher, and radio beacon, also need an individual battery unit. These batteries are housed in each instrument capsule.

3. Electromagnetic Interference of Geophones

Generally, some magnetism will leak out of the metal container of a moving-coil type geophone as used in this OBS. In the case of the use on land, the effects of leaking magnetism can be avoided by separating sensors at an adequate distance. In the case of the OBS, however, the three geophones must be installed together in a small gimbal case, so that there may be some mutual interference. Thus, the seismic waveforms could be distorted by the effect of induced magnetism. For this reason we performed an experiment using a shaker table. We carried out the experiment using the same geophones as installed in the present OBS; (i) a geophone was set on the shaker table and its frequency character between 0.5Hz and 80Hz was examined; (ii) another geophone was set orthogonally as close as in the OBS gimbal case to the above geophone and the same examination was made as in (i). The result of this experiment is shown in **Fig. 2**. In both cases (i) and (ii), the frequency characters for the geophone were identical. This result allows us to neglect any interaction between geophones installed within the small space of the gimbal case.

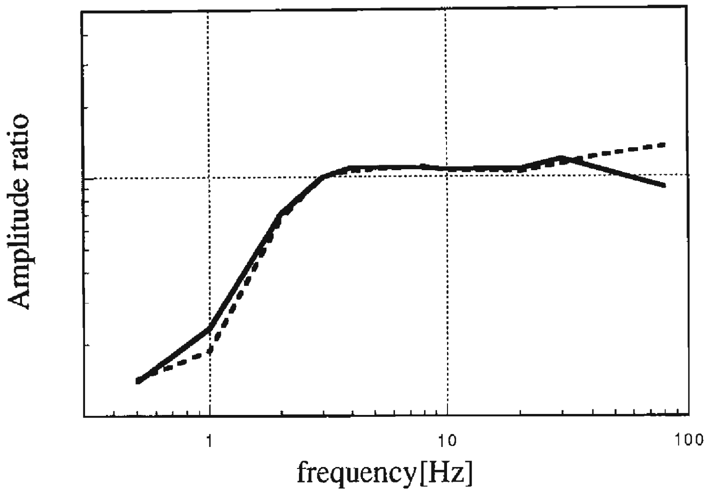


Fig. 2. Frequency characteristic of the horizontal seismometer. The solid line shows the case of a single seismometer and then broken line shows the case of two orthogonal moving-coil type seismometers. Both axes have a logarithmic scale.

4. Examples of seismogram

A test driving the present OBS was performed at the Abuyama Observatory, Kyoto University. The examples of data are shown in **Fig. 3**. In this observation, the OBS and the same kind of reference geophones with the OBS is equipped were set on the same concrete block at the basement of the observatory. The output of each geophone was recorded with recorder units of the same type used in the OBS. Since the recorder needs a commercial electric power supply for this land experiment, the upper hemisphere of the pressure case was removed and only the lower hemisphere and hard-hat were kept in place. The recording conditions such as the gain of the pre-amplifier and sampling frequency were kept the same for both seismometers.

Fig. 3 (a) shows that the waveform of a vertical component recorded by the OBS is almost the same as recorded by the reference geophone. On the other hand, in **Fig. 3 (b), (c)**, the waveform and spectrum of horizontal components recorded by the OBS differ a little from those recorded by the reference geophone. From **Fig. 3 (c)**, however, it can be seen that this difference takes place only at frequencies around 15Hz. The spectrum for both geophones are quite consistent except for the above frequency range. If the silicon oil contained in the gimbal case could not keep the geophones in the vertical direction, its effect would appear particularly in long-period horizontal components and thus deform the waveforms. It is difficult to attribute this difference around 15Hz to the effect of silicon oil dumping. It may be the result of only the lower hemisphere and hard-hat being in placed. However, from the results shown in **Fig. 3 (b), (c)**, no remarkable effect appears in the seismograms. We therefore conclude that the silicon oil performs its function effectively for seismic observation.

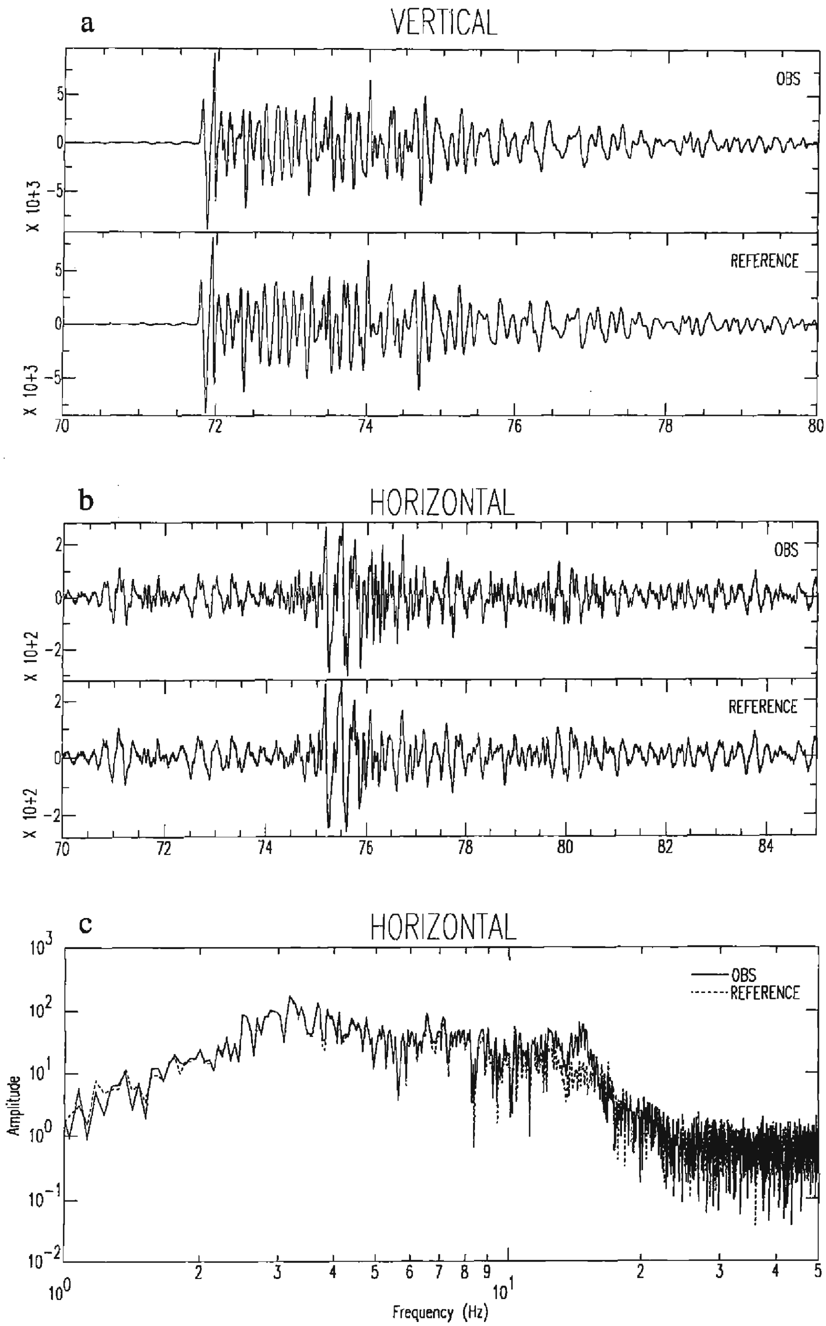


Fig. 3. Examples of data recorded by the new OBS at the Abuyama Observatory, Kyoto University. "OBS" shows the records by OBS and "REFERENCE" shows those by reference geophone set on the same block with the OBS. (a) Example of a vertical component. (b) Example of a horizontal component. These two wave forms are a little different from each other. (c) Spectrums of the data shown in Fig. 3 (b). Two spectrums are very similar to each other except for the frequencies around 15Hz. Waveform and spectrum plots were made using SAC coded by Tull (1988).

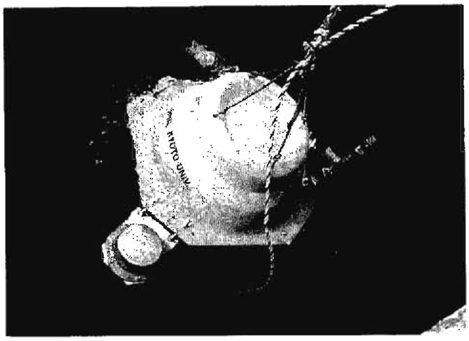


Photo. 5. A photograph of OBS popping up at the release test performed at the Iwaya Port, Awaji Island. At the time of this test, the radio beacon was not mounted.

5. Release test

All data recorded during the entire observation period can only be stored in the OBS. It is thus essential in the OBS observation to retrieve the OBS after completing observation. The release system used in this newly developed OBS must be examined for its reliability in the sea itself. The tests for this purpose were performed at Iwaya Port, Awaji Island, Hyogo Prefecture. The depth of water in this port is as shallow as 5m, however, enough for this test. The actual release test was performed twice. We set the OBS on the seafloor by free-fall and then transmitted the acoustic release command to the OBS; the OBS began the electrical corrosion. In the first test, the releasing procedure was completed and the OBS floated to the surface in 9 minutes, and in the second test in 8 minutes (**Photo. 5**). In addition, the buoyancy of the OBS was confirmed. From the results of this test, it is considered that the release system used in this model is reliable.

6. Conclusion

The previous models of Kyoto University OBSs were designed to operate with the aid of a submersible vessel as mentioned before. They were relatively heavy and were inoperable for long periods because of their high consumption rate of electric power and small memory capacity. Our newly developed OBS, however, has a low rate of electric power use and a large memory capacity and is relatively easy to handle compared with the former types of Kyoto University OBSs. This OBS can be operated for long periods and record many seismic data. The tests in shallow sea enabled us to apply the OBS to conditions of the deep seafloor. Further improvements to be made to the OBS are summarized as follows; 1) installation of a compass for defining the direction of the three-component geophones and 2) application of the OBS placed by submersible vessel like the former types of Kyoto University OBSs.

Acknowledgment

The release system designed by Dr. H. Baba was referred to when designing our system. The electric corrosion unit used was designed by Dr. T. Kanazawa. Dr. H. Inokuchi and staff members of the Marine Biological Station, Faculty of Science, Kobe University, provided invaluable assistance in the release test. We express our thanks to these people. We thank also the Section of Earthquake Ground Motions, Disaster Prevention Research Institute, Kyoto University, for allowing us to use the shaker table.

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