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Ocean Bottom Seismometer Handled by Submersible Vessel and Its Observation Prior to the 1993 Hokkaido Nansei-Oki Earthquake

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Abstract

Nowadays, most ocean bottom seismometers (OBS) are of the free-fall and pop-up type. For the observations, they are dropped from ships and self land on the flat sea floor where generally thick sediments cover basement rocks. However, soft sediment affects and distorts incoming seismic signals. If we could place ocean bottom seismometers on hard rock, it could produce high quality seismograms which contained more information on structure and earthquake sources. For this purpose, a submersible vehicle is necessary as it can carry and place an OBS properly on exposed sea floor hard rock.

We designed a new type of OBS which can be handled by a submersible vehicle. This new OBS contains instruments within two aluminum cylinders with syntactic foam blocks outside the cylinders for buoyancy. The submersible vessel, Shinkai-6500, was used to set the OBS to observe seismicity in the Okushiri Ridge Area. It was placed on a relatively flat and hard basement outcrop at a depth of 3338m. The OBS was released to the sea surface through a self pop-up system after two days of observation.

During this observation period, we noticed very high micro-earthquake activity around the Okushiri Ridge area where one year later the Hokkaido-Nansei-Oki earthquake of M7.8 took place. Such seismic activity could not have been detected by land-based seismic networks alone.

1. Introduction

The first generation of ocean bottom seismometers (OBS), prior to the development of the pop-up type OBS, was of the anchored-buoy type. The OBS of this type were very large, heavy, and needed very long ropes to moor a buoy at the sea surface. Deploying these OBSs required enormous time, manpower, and a large ship. For example, to deploy one anchored-buoy type OBS in a trench area deeper than 6000m takes nearly 24 hours of operation. For this reason, few OBSs could be deployed simultaneously.

The free-fall and pop-up type OBS were developed in the 1970s in Japan (Kasahara et al. 1979, Nagumo et al. 1981). These OBS were much smaller and easier to handle which allowed us to conduct array observations using a number of them for the observation of natural earthquakes and surveys of the crustal and mantle structure beneath the ocean. At present, pop-up OBS are therefore used mainly for ocean bottom seismology except for some permanent routine observations which require connection with cables.

Since these pop-up type OBS are dropped from the sea surface, the position of the

OBS as it settles on the sea floor is not precisely known. The seismometers likely drift during drop off into the sea by ocean currents. Furthermore, we also cannot control the coupling conditions of the OBS to the sea floor sediments. In general, we avoid rough ocean bottom topography to escape the risk of destruction or overturning of the OBS when it lands on the sea floor. The OBS landing sites are therefore placed in areas with flat topography. However, flat sea floors are mostly covered with thick piles of unconsolidated sediments that largely distort incoming signals upon entering such sedimentary layers. For similar reasons, it is also rather difficult for long period waves to be recorded at a proper signal to noise ratio. The above-mentioned disadvantages in deploying pop-up type OBS likewise make it difficult to develop strategies to study oceanic structures and earthquake source mechanisms.

However, if a submersible vehicle were available, it could transport an OBS and place it on exposed hard rock at sea floor. This could be done with a manipulator operated by a person viewing the OBS. Once the OBS is properly installed in this manner, only then could high quality signals be expected to be recorded. Using this method, we could place an OBS safely even in areas of rough topography such as the terrace of a steep cliff. Furthermore, the precise position and orientation of the OBS could also be determined by the navigation system of the submersible vehicle.

In this paper we describe the recent development of an OBS which can be transported and installed using a submersible vehicle. We also show some examples of seismogram records which were obtained in the Japan Sea, off the west coast of Hokkaido.

2. Newly designed OBS

At present, a glass sphere is used as an anti-pressure case for almost all pop-up type OBS. The glass sphere is light-weight, inexpensive, and sustainable at depths down to 6000m. Nevertheless, glass spheres are fragile particularly against mechanical shocks. The risk of implosion must always be anticipated if a submersible vehicle handles a glass-sphere OBS. For this reason, a glass sphere is not generally practical for a submersible to carry.

In order to overcome this difficulty, we designed a new OBS. This new OBS has two aluminum cylinders (12 cm diameter) as pressure cases. One of these cylinders is equipped with electric circuit boards and a seismometer unit. The other cylinder is equipped with batteries for all electrical power supply needs. These two cylinders are connected by a water-tight cable (Fig. 1). The seismometer we used is a VSE-150 model manufactured by Tokyo Sokushin Co. It is equipped with 3 component force-balanced velocity meters within a small container. The frequency characteristics of these sensors are flat at velocity ranges of 0.1Hz to 100Hz. In comparison, most OBS developed in other institutes are equipped with moving-coil type geophones with a pendulum period of 2-5Hz. The VSE-150 model, however, is a sensor covering a wider range of frequencies. Since the three components are all force-balanced, they are identical to each other. The sensors also do not require maintainance along a fixed vertical

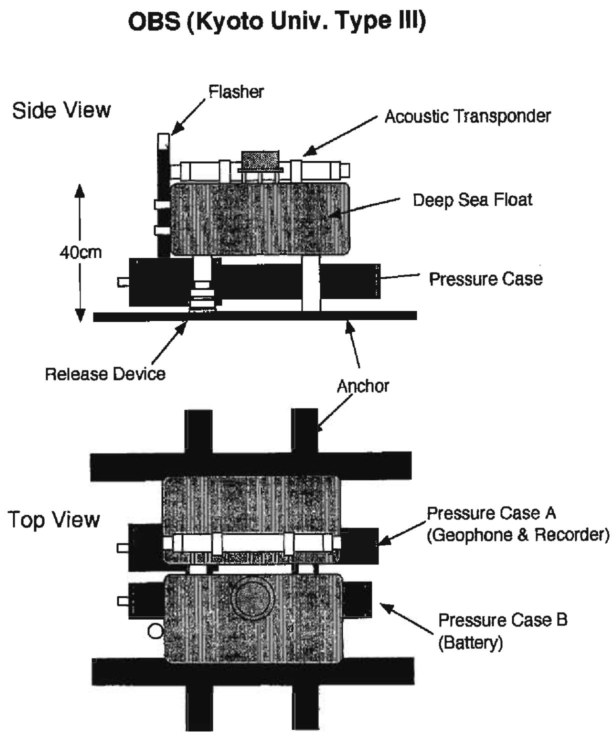

Fig. 1 Ocean bottom seismograph (Kyoto Univ. Type III) newly developed for the operation of the submersible vehicle.

or horizontal coordinate as the three components are balanced with electomagnetic forces.

The recording unit was modified from a unit used in the previous KU type II model (Tsutsui et al. 1989) and was made to fit into the cylinder by redesigning the circuit boards. Analog signals transmitted from the seismometer were digitized by an analog/digital converter (12bits, 50Hz sampling). The in-house microprocessor of the recorder continuously calculates both the long term average (LTA) and short term average (STA) of incoming seismic signals. When the STA exceeds the LTA, the recorder generates a trigger signal to start the recording. Seismic signals are stored in EP-ROMs (Erasable Read Only Memory) upon receiving the information on the timing of the trigger. The total amount of available EP-ROM storage is 12MB in which more than 700 event records (3 components, 54 sec. long each) can be recorded.

This recorder also has a built-in thermometer and a tiltmeter. At every on the hour, the temperature and tilt of the OBS are recorded automatically into the memory. All recording parameters, clock adjusting, start time of recording, trigger levels of LTA and STA etc., are all provided by an external personal computer connected through an RS-232C cable. The seismic data recorded in OBS are also transferred to a personal computer through the RS-232C cable.

At the top of the OBS, an acoustic transponder system contained in a separate pressure case (manufactured by KAIYO DENSHI CO.) is attached. After the end of observations at the sea floor, a pop-up command is transmitted from a surface ship. Receiving the signal by the OBS's transponder, electric current is transmitted to a releasing device. The stainless plate of the release device which connects to the main part of the OBS above and the anchor below then starts to be dissolved by electric corrosion. The OBS is detached from the anchor, and eventually pops up by buoyancy. Buoyancy force is provided by a deep sea float made of syntactic foam attached to the pressure cases. This releasing device was first developed by Yamada et al. (1981).

The present OBS system was purposely designed to be handled by one person and can be disassembled into small parts, quickly reassembled, and is very portable. The total weight of the system is 120kg in air, and only 16kg in sea water. The net buoyancy without anchor is about 10kg.

Tests for both the acoustic release and pop-up systems were performed off the coast of Awaji Island in March, 1992. Another test for the metal pressure cases and the recording system was carried out at the Minami-Ensei Knoll (2823N 12738E, depth 700m) using a submersible Shinkai 2000 of JAMSTEC (Japan Marine Science and Technology Center) in May, 1992. Both tests were successful.

3. Observation

3.1 Installation by Submersible Vessel

On August 1, 1992, a test observation was performed using the submersible SHINKAI 6500 of JAMSTEC. The OBS site lies along the western foot of Okushiri

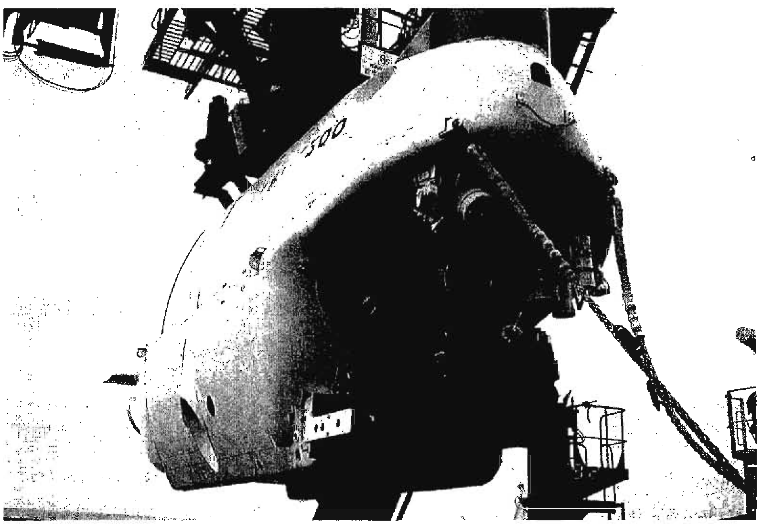

Fig. 2 Ocean bottom seismograph loaded in the sampling basket of the submersible Shinkai 6500.

Ridge, west of Hokkaido. SHINKAI 6500 loaded the OBS in its sample basket (Fig. 2), dived, and arrived at the sea floor in 90 minutes. The sea floor at this site is gently sloping and not covered by sediment. The location of the site was at 44.05N 139.05E, and 3338m deep. The OBS was set using the two manipulators of the submersible. The operation was very easy and was completed within 5 minutes.

After a 2-day observation, the OBS was retrieved. The release command, which consists of acoustic signals, was emitted from the mother ship YOKOSUKA. The floating speed was 40m/min and the OBS was successfully recovered in about 90 minutes.

3.2 Results

A total of 21 events was recorded during the 2-day period of observation. Some examples of the seismograms are shown in Fig. 3. Low-frequency background noise with large amplitudes were observed to overlap almost all event records (Fig. 3 (a)). The period of the noise was about 5 seconds, and the peak to peak amplitude was about

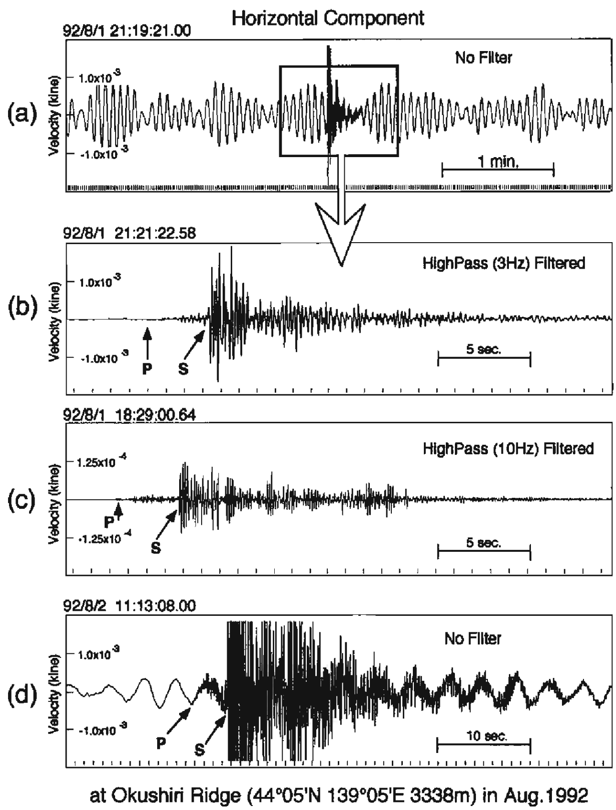

Fig. 3 Example of a seismogram recorded during the test observation in August 1993 at the Okushiri Ridge Area. All seismograms are horizontal components. High-pass filter was adopted for (b) and (c). The seismogram in rectangle of (a) is shown as (b). Unit of amplitude is kine (cm/s).

2mkine. The noise level was very high until August 2, and gradually diminished during the latter half of the observation period. Since the sea was rough from August 1 to 2, the weather became calmer afterwards, the recorded noise was possibly caused by the rough sea waves. Before this study, the effect of sea waves near the sea surface on ground motions at the seafloor deeper than 3000m was thought to be negligible. We think that the sensors used in our OBS are more sensitive to long-period signals than those in other OBS using short-period sensors. In addition, the two pilots and observer at the dive site of the SHINKAI 6500 noticed very fast ocean currents even at the sea bottom. Surprisingly, the sea floor in this area lacks soft sediments even though the topography is almost flat. Thus, it is a strong possibility that fast bottom currents along the Okushiri Ridge sweep sediments out and produce the long-period noise recorded by the OBS.

In the event files, three local natural earthquakes were recorded. Two of them had very small amplitudes, buried within the low frequency noise. The trigger for these two events was the noise rather than any seismic signal. Therefore, the seismic signals were recorded by chance. By digitally filtering the data, we can remove the low frequency noise and observe clear signals (Fig. 2 (b) and (c)). Another example has a larger amplitude, and was triggered by the seismic signal itself. At the time when this event occurred, the low frequency noise diminished. The epicentral distance for these earthquakes based on the S-P time was nearly 20km. The magnitude of the event shown in Fig. 2 (b) estimated by maximum amplitude and epicentral distance was about 2.0. One teleseismic event was recorded in addition to the three local events. The long period seismic coda of this teleseismic event was clearly recorded.

3.3 Seismicity in the Okushiri Ridge Area

Even though the observation period was only 2 days, we were able to detect 3 local earthquakes near the OBS site. In comparison, the seismicity of the area seems to be quite low based on the data obtained by the land-based seismic network. In Fig. 4, the epicentral distribution is shown based on the JMA (Japan Meteorological Agency) data over the last 4 years (1989-1993). It is notable that only a few earthquakes are plotted on this map around the OBS site. Considering that the detection capability of the OBS was reduced by the overprinting of the low frequency noise, we can infer that more micro-earthquakes could be expected to occur in this area. In fact from the present study, we may safely say that the seismicity around the Okushiri Ridge is usually very active but most of the events have not been detected.

Since the Nihonkai-Chubu Earthquake (M7.7) in 1983, many scientists considered the Northeastern Japan Arc as part of the North American Plate, with a plate boundary between the Eurasian Plate and the North American Plate along the Eastern Japan Sea area (e.g. Kobayashi 1983). Many great earthquakes have taken place along this boundary. One year after our observation, the Hokkaido-Nansei-Oki Earthquake (M7.8) occurred south of the OBS site on July 14, 1993. The Shakotan-Hanto-Oki Earthquake (M7.0) also occurred just beneath the OBS site in 1940. Subsequently, much geological evidence proving the existence of a plate boundary in the area has been published. (e.g. Tokuyama et al., 1992) The Okushiri Ridge is believed to have been formed by east-west

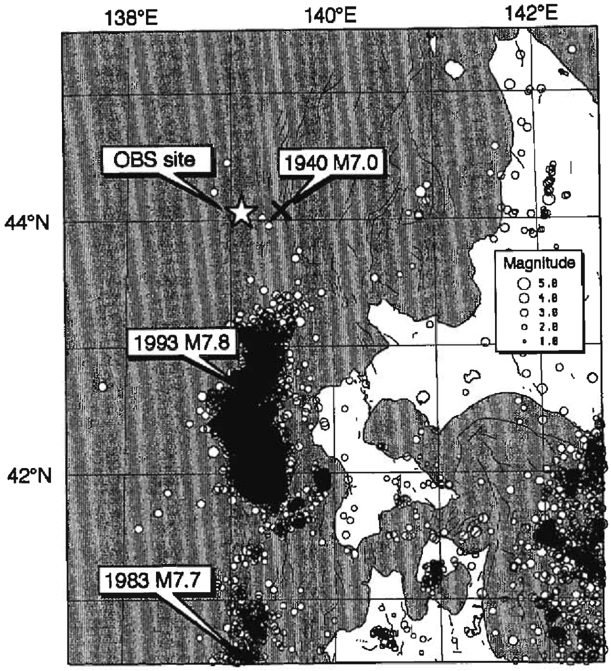

Fig. 4 Epicentral map of earthquakes shallower than 100 km in the area off western Hokkaido. (1989-1993, by the Japan Meteorological Agency.) The star shows the test observation site of the new OBS. Epicenters of great earthquakes are also plotted.

compression along this plate boundary.

The activity we found may be a general feature of the plate boundary. Or, is this activity simply an aftershock of the great earthquake of 1940? Because of the lack of OBS data of this area, we can not decide which explanation is valid. Ocean bottom seismic observation is very important to know more about the tectonics of this plate boundary and to plan additional studies that would help to prevent tsunami disasters caused by great earthquakes in this area.

4. Subjects for Future Improvements

The low frequency noise observed in this study was probably caused by sea surface waves and sea bottom currents. However another plausible cause of the noise can be attributed to movement of the OBS itself as a result of its light weight in water and a weak coupling with the sea floor. Past studies have shown that deployment of the OBS on sediment layers is not appropriate for getting precise seismic waveforms. On the other hand, sediment may actually help the OBS to couple more securely to the sea floor. The present OBS was not sufficiently heavy because of the capacity load limit of the submersible (which in this case is about 20kg in water). If we use a light weight OBS, then we may need to fix it more firmly to the rock using cement or similar types of anchoring materials.

However, using a submersible to retrieve the OBS would eliminate the use of self pop-up devices. The OBS could then be equipped with more batteries or other power source devices. Should the balance of the OBS need to be altered, then the coupling mechanism to the sea bottom should also be made much tighter.

In this study, the OBS was equipped with servo-type seismometers to conduct semi-long period seismic observations. However, using this type of sensor limits the total observation period to within 10 days as they need a constant source of electric power supply. Therefore, for long term observations it is necessary to replace the servo-type sensors with passive sensors such as moving coil-types, or alternatively, increase the capacity of batteries.

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