NEW COMPACT OCEAN BOTTOM CABLED SYSTEM FOR SEISMIC AND TSUNAMI OBSERVATION

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Abstract: It is essential to observe seismic activities on the sea floor just above the seismogenic zones where large earthquakes have been occurred. As an ocean bottom cabled system (OBCS) is the best instrument to observe seismic activities, we have been developing a new OBCS system. The concepts of the development are a compact observation node and a low cost of the system. Utilization of the up-to-date Information and Communication Technologies enables to reduce a size of the observation node and a cost. Reliability of the system is kept by using redundant system. We have a plan to install the new OBCS system to Japan Sea in 2010. This cable system has total length of 25 km and 4 observation nodes with 5 km interval.

1. INTRODUCTION

The Japanese islands are positioned near the subduction zones. Because large earthquakes have repeatedly occurred in subduction zones, it is important to observe seismic activities on the sea floor just above these seismogenic zones using Ocean Bottom Seismometers (OBSs). Although a recording period of recent pop-up type OBSs reaches more than one-year[1], the pop-up type OBS have disadvantages such as limited power, data recovery reliability, off-line observation for long-term seismic observation on the seafloor.

Ocean Bottom Cabled Seismometers (OBCS), where the sensors are equipped in a hermetically-sealed case and these cases are connected with cables, is the best solution to address these problems. An OBCS, consisting of a few cabled seismometers (CSSs), was developed based on a submarine telecommunication cable system, and have been used over the past 25 years in Japan.

Although the existing OBCS have realized a significant contribution to the study of seismic activity, the number of seismometers is insufficient for high resolution observations of the seismogenic zone. It is undoubtedly a problem of cost that needs to be resolved in order to consider a sufficient number of seismometers. This is the critical problem in the existing OBCS [2].

All aspects of ICT technologies have been studied, and it was concluded that ICT (Information and Communication Technologies) should be utilized for a new OBCS, i.e., IP (Internet Protocol) at the bottom of the ocean. According to this concept, we have been developing a new OBCS system. The new OBCS system can be made compact since a software processes various measurements, while complex and a large amount of hardware
are used in the existing OBCS. Reliability of the system is kept by using redundant system which is easily constructed using the ITC.

We have a plan to install the new OBCS system in Japan Sea during 2010. The cable system has total length of 25 km and 4 observation nodes with 5 km interval. In this paper, we will describe the new compact OBCS system in detail and present a plan for the first installation.

2. OBJECTIVES OF THE NEW OBCS

There are already approximately 2,000 land-based earthquake observatories in Japan. On the other hand, the number of earthquake observatories in the oceans is quite limited, and furthermore, they are configured in a line. Our objective is to develop a high density of observation stations in the marine seismogenic areas that will be sufficient to achieve the same level of observation as the land-based networks. Seismic observations in the ocean should be performed over a planar area rather than only over a line of seismic stations.

Cabled Sensors (CSs) are equipped with optical cables and placed at 20 km intervals. Optical cables are installed for 900 km as a maximum with a continuous “S” pattern, by which the CSs are distributed two-dimensionally (Figure 1). Therefore the earthquake observatories are carried out using a network, and the density of seismic stations on the ocean bottom would be equivalent to that on the land. When this system is used at the maximum length, it is composed of 40 CSs.

The accuracy of the time stamp should be less than 0.1 ms, which is equal to the present accuracy of the land seismic network. The system is expected to be in use for more than 20 years.

The most important objective of the new OBCS is low-costs of both production and installation. The size of the CS is a key to achieve this requirement. When the CSs are sufficiently small, the installation costs can be reduced.

The cable network configuration of the OBCS adopts two dual methods, i.e., one is a ring configuration, and another is a doubled ring configuration. A CS is equipped to a ring at 40 km intervals, i.e., a CS is installed with 20 km intervals on the sea floor using the doubled ring of network. Ethernet, which is a de-facto standard in ICT, is used as data transmission system for this doubled ring configuration (Figure 2).

Data collected with a time stamp at each CS are transmitted using standard IP data transmission to landing stations. The two landing stations are equipped with a power supply, a storage system, and access to the Internet. A GPS clock at each landing station is used as a time reference to synchronize timing of each CS, and is fed
to each CS through a dedicated line, i.e., Ethernet is not used. Methods of clock transmission have been studied, and it was found that the latest clock synchronization system over Ethernet is sufficient for OBCS [3].

In addition, IEEE-1588 is useful for a land-based system clock synchronization method, as the number of fibers is reduced. We evaluated clock accuracy of IEEE-1588, and found that error of timing is less than 200 ns through the switches (Figure 3). However, it was decided that a simple dedicated line for clock distribution should be used, because for a system in the ocean: 1) a dedicated line is not so expensive, and 2) a simple configuration can realize high reliability. This dedicated line is also used for control of the CS system.

Figure 3. Accuracy measurement of IEEE-1588

Software is capable of processing various measurements. Using software make the CS compact. In addition, observation parameters can be change from the land, thus enabling detailed and investigative measurement. Finally, software continuously monitors the status of parts, and alerts when necessary (e.g., power down of laser transmitters).

The performance and reliability of Linux have been evaluated and it was concluded that Linux is a mature OS that is acceptable for use with the OBCS. Each Linux OS can be accessed from both landing stations. Additionally, the Linux OS can be restarted from landing stations through the dedicated clock line (not Ethernet lines). There is a possibility that the Linux cannot realize sufficient real-time processing due to its performance. To avoid this problem, sensor data should be processed with a high priority mode (an interrupt mode is used only for sensor data).

3. DEVELOPMENT OF NEW OBCS

The new OBCS system was developed. The Linux OS is able to access two Ethernet lines. The clock module derives a precise clock generated from a GPS clock from the landing stations, as well as control signals such as Linux restart. The developed Linux board has SH-4 micro-processor which is a widely used industrial microprocessor. The field-programmable gate array (FPGA) on the board handles the interface to a digitizer, and stores 30 ms of data. Linux retrieves data every 30 ms and then sends it to the landing stations. The performance of the Linux OS has been evaluated. The result also indicates that the combination of the SH-4 CPU and the Linux OS is capable of handling approximately 40 times of the required measurement operations. The Ethernet switches in each CS are produced using another FPGA.

The seismometer is a conventional force balance accelerometer, which is a single axial type. This accelerometer has been used for the existing ocean bottom cable systems. Each output of three accelerometers is synchronously digitized by 24 bit sigma-delta A/D converters with a sampling rate of 1 kHz. A GPS clock signal from the landing stations is directly input to the digitizer, so that accurate 0.1 ms time stamping is guaranteed using 100% hardware. In addition, a precise pressure gauge can be used for tsunami observation. An interface for the pressure gauge has already been equipped in the Linux board.
Consolidated studies for packing of the CS have also been performed, because the size of the CS is a critical for minimization of the costs. First, we developed electronics unit of the CS as small as possible. Figure 4 shows newly developed electronics unit. There are only 5 boards; Linux, Ethernet switches and two digitizers in three boards for the CS. Size of each board is approximately 7×7 cm. The boards are stacked.

In addition to the electronics unit, three seismometers, power unit including zener diodes, and six SPFs must be mounted into one package. A size of the CS package is 10 cm diameter and 30 cm long, which is almost equal to that of a 2 L plastic drink bottle (Figure 5). A pressure vessel for the new developed CS package was also developed. A Size of the pressure vessel is 13 cm in diameter and 50 cm long. Due to its small size of the capsule, total size of the CS became smaller than that of the existing CS [4]. Compared to the existing OBCS, which has a 22 cm diameter and is 150 cm long, this is a remarkable reduction in size (Figure 6).

4. FIRST INSTALLATION PLAN

Global Positioning System (GPS) observations with a dense station distribution by the Geographical Survey Institute, Japan revealed that the central coastal area of the Japan Sea has large strain rate, which is named the Niigata-Kobe Tectonic Zone (NKTZ) (Figure 7). Historical large earthquakes have occurred in and around the NKTZ, and the large strain rate was estimated to induce the large earthquakes. Recently, there were three large earthquakes (e.g. the 2007 Chuetsu-oki Earthquake) in and around the NKTZ. Precise seismic activity which may be induced by the large strain rate should be understood. Therefore, we decided to install the first practical OBCS system in the marine area of the NKTZ. The system will be installed during 2010.
The practical OBCS system for the first field installation has a total length of 25 km and 4 CSs with 5 km interval. Each CS has three-component accelerometers. There is only one landing station due to limitation of the cable length. Therefore the Ethernet channel is adopted to be turned at the end of the cable. The data transmission channel using the Ethernet is duplicated. The clock module also has duplicated channel for redundancy. At the landing station, the data are stored in a large disk array system. In addition, the data from the CSs are transmitted to the data and control center at Earthquake Research Institute, the University of Tokyo in Tokyo. The system control commands will be sent from ERI.

5. CONCLUSIONS

The new OBCS has been presented in detail. ICT has enabled the new OBCS to become more compact and less expensive, and enabled IP access and the upgrade of OBCS for the flexibility and expandability of measurements. The ICT-based OBCS system has remarkable advantages:
1) A new compact OBCS can be made so compact since software processes various measurements.
2) The compact OBCS is not expensive for both production and installation.
3) Reliability of the system is kept by using redundant system which is easily constructed using the ITC.
4) Because of a software-based OBCS, it will be possible to change measurement parameters of seismometers after installation.

The CS of the new OBCS has been developed. A size of the pressure vessel for the developed CS is 13 cm in diameter and 50 cm long. We have a plan to install the first system in 2010. The first system has a total length of 25 km and 4 CSs with 5 km interval and will be deployed during 2010 in the coastal area of the central Japan Sea, where large earthquakes occurred recently.

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7. REFERENCES


