INSTALLATION OF NEW SEAFLOOR CABLED SEISMIC AND TSUNAMI OBSERVATION SYSTEM USING ICT TO OFF-TOHOKU REGION, JAPAN

Masanao Shinohara, Tomoaki Yamada, Shin'ichi Sakai, Hajime Shiobara (Earthquake Research Institute, the University of Tokyo) and Toshihiko Kanazawa (National Research Institute for Earth Science and Disaster Prevention)
Email: mshino@eri.u-tokyo.ac.jp

Earthquake Research Institute, the University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-0032, Japan

Abstract: We have developed the new compact Ocean Bottom Cabled Seismic and Tsunami (OBCST) observation system using Information and Communication Technology (ICT) since 2005. Our system is characterized by securement of reliability by using TCP/IP technology and a software-based observation node using up-to-date electronics technology. In 2015 September, we installed the system off Sanriku, northeastern Japan to obtain exact seismic activity related to plate subduction such as the 2011 Tohoku earthquake and to observe tsunami on seafloor using two cable observation systems. The observation had been performed just after the deployment of the system.

1. INTRODUCTION

Geophysical observations by using seafloor cabled system are useful in marine environment because the cabled system enables real-time and long-term observation. The Pacific plate is subducting below northeastern Japanese islands, and several destructive earthquakes recorded in history occurred in association with the subduction of the Pacific plate. Seafloor cabled system is powerful tool for study of the plate subduction and earthquake generation. Therefore seafloor cabled system with seismometers and tsunami-meters was developed based on a submarine tele-communication cable system, and have been used over the past 25 years in Japan [1, 2].

For the existing seafloor cabled systems, the number of the equipped seismometers is insufficient for high resolution observations of seismic activities in marine area. Construction cost should be lowered and the existing seafloor cabled system does not have sufficient for multidisciplinary observation and flexibility of measurements after installation [3-7].

To resolve the problems of the existing seafloor cabled system, we concluded that seafloor cabled system of the next generation should use Information and Communication Technologies (ICT), i.e., Internet Protocol (IP) on the seafloor. According to this concept, we have been developing an Ocean Bottom Cabled Seismometer and Tsunami-meter (OBCST) system. The OBCST system can be made compact since a software processes various measurements, while complex and a large amount of hardware are used in the existing seafloor cabled system. Reliability of the system is kept by using redundant system which is easily constructed using the ICT [8-10].

2. CONCEPT OF OBCST SYSTEM

In concept of the OBCST system, Observation Nodes (ONs) are equipped with optical cables and placed at 20 km spacing (Figure 1). Optical cables are laid for 900 km in maximum with a continuous “S” pattern, by which 40 ONs are distributed two-dimensionally [3-7]. The important objective of the OBCST system is low-costs of both production and installation. A smaller size of an ON leads to lower costs for installation. When the ONs are sufficiently small, ordinary ships, rather than specialized cable ships that are used for the existing cabled system, can be utilized to install the OBCST system, and the installation costs can be significantly reduced.

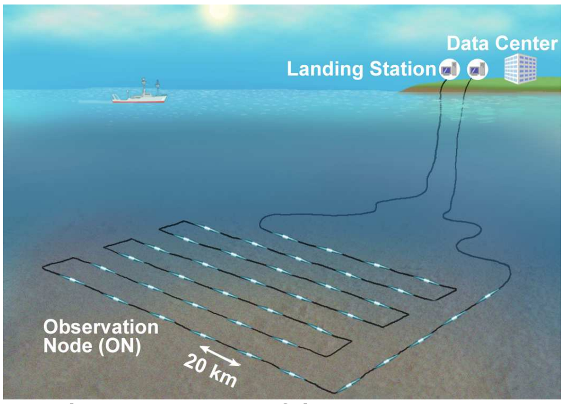

Figure 1: Concept of the OBCST system (modified from [9])

Communication of the OBCST system adopts two dual methods, i.e., one is a ring configuration, and another is a doubled ring configuration [3-11]. An ON is equipped to a ring at 40 km intervals, i.e., an ON is installed with 20 km intervals on the seafloor using the doubled ring of network. This scheme is employed to enable both high reliability and low cost. Ethernet, which is a de-facto standard in ICT, is used as data transmission system for this doubled ring configuration. The first system based on this concept was developed as Ocean Bottom Cabled Seismoemeter (OBCS) system and deployed in Japan Sea [9-11].

3. DEVELOPMENT OF OBCST SYSTEM

ERI had installed seismic and tsunami observation system using seafloor optical fiber in the off-Sanriku area for seismological study in 1996. This seafloor cabled system is based on the tele-communication technology, and seismic waves and tsunamis had been observed continuously in real-time since the deployment of the system. The 2011 Tohoku earthquake has the largest magnitude in instrumental record of Japan and the hypocenter was positioned at a plate boundary between the Pacific plate and the landward plate below a landward slope of the Japan Trench [12]. The system observed seismic waves and tsunamis generated by the 2011 Tohoku earthquake, and sent data to the ERI until 30 minutes after the mainshock occurrence. However, the landing station of the system was damaged by the huge tsunami, and an observation has been discontinued. The data from the system are essential to estimate accurate position of the source faults and the source process of the 2011 event [13,14]. Because the system is dispensable to obtain data from the seafloor in real-time, we decide to restore the existing system. In addition, we made a plan to develop the new system based on the concept of the OBCST system and install the new system for additional observation and/or replacement of the existing system.
The developed OBCST system for off-Sanriku area is characterized by using TCP/IP and up-to-date electronics [15]. The OBCST system for off-Sanriku has both seismometers and tsunami-meters as scientific sensors. We selected high-

precision pressure gauge using crystal oscillator (Paroscientific Inc. series 8B) as a tsunami-meter. A pressure gauge outputs measurement as changes of frequency of oscillation. A micro-processor unit has an interface of a pressure gauge and counting unit of frequency of oscillation. A micro-processor board is controlled by a processor of SH-4 and an FPGA on the board handles the interface to a digitizer for seismometers and pressure gauge. Linux system is implemented on microprocessor board to control all system. A seismometer is a conventional force balance accelerometer (JA-5TypeIII, Japan Aviation Electronics Industry, Ltd.). Analog signals from three accelerometers (X, Y, Z components) are synchronously digitized by 24 bit sigma-delta A/D converters with a sampling rate of 1 kHz. A time window for counting frequency of oscillation from pressure gauges is 1 ms and a reference clock for counting is sent from GPS clock in a landing station. Resolution of pressure measurement corresponds to less than 1 mm height change of sea surface. The OBCST uses standard TCP/IP protocol with a speed of 1 Gbps (Figure 2) for data transmission, system control and system monitoring. Increase of speed of data transmission enables us to collect larger amount of data. The Wavelength Division Multiplexing (WDM) is also introduced to reduce number of optical fibers.

High-precision timing is important for seismic observation. Therefore, clock is delivered to all observation nodes from the GPS receiver on a landing station using simple dedicated lines. The clock lines are also used for communication to Linux system when the TCP/IP network is not available. The observation node has atomic clock module with accuracy of smaller than 10^{-8} for a case that delivery of clock form a landing station is stopped. In addition, IEEE-1588 (Precision Time Protocol, PTP) is implemented in the OBCST system to synchronize a real-time clock in observation node to a land-based system clock driven by GPS through TCP/IP protocol. We evaluated clock accuracy of implemented IEEE-1588, and found that an error of timing is less than 300 ns through the switches [15].

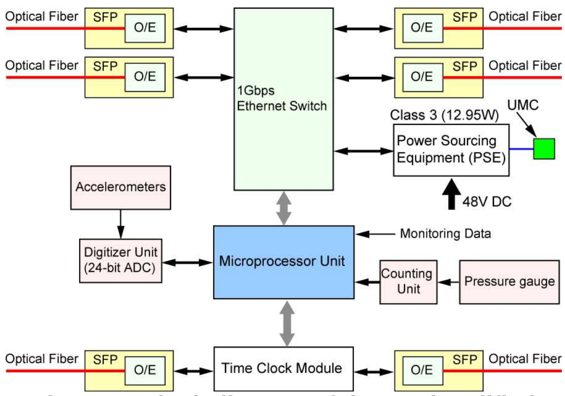

Figure 2: Block diagram of the ON (modified from [15]).

We produce two types of ONs. Both types have three accelerometers as seismic sensors for three-component ground motion observation. One type of ON (Type FA) equips a pressure gauge as tsunami sensor in the inside of the pressure vessel. Another type (Type FB) has an external port for additional observation sensor. Power of additional sensors on seafloor is supplied using Power over Ethernet (PoE) technology. Because the our system has Ethernet switch in an internal unit of observation node (Figure 2), it is not difficult to implement PoE port. We developed the power sourcing equipment (PSE) unit for PoE. The PSE provides an electric power of about 13 W to additional sensor and 10 Mbps Ethernet is used for data transmission and communication. Because an underwater mateble connector (UMC) is used as the external port, an additional sensor can be replaced after the deployment of the cable system. For both types of ONs, four electric lines must penetrate the pressure capsule. We developed feed-through technology for four metal conductors. This means that our pressure capsule does not use an underwater connector at all. For a pressure vessel, a smallest size of standard canister of tele-communication seafloor cable system is used to reduce cost. The capsule for observation node has diameter of 26 cm and length of about 1.3 m. This small size of the canister has an advantage for burying the system below seafloor.

4. INSTALLATION OF OBCST SYSTEM TO OFF-TOHOKU

The existing Sanriku cable system has been restored by rebuilding of the landing station and receiving unit of the cabled system. In addition to the existing system, we installed the developed OBCST system for additional observation and/or replacement of the existing system. The system has a total cable length of 105 km and 3 observation nodes with 30 or 40 km spacing. Two ONs are type FA, and the furthest ON is Type FB. At the deployment of the cable system, we attached a precise pressure gauge with digital output to Type FB. Consequently, all the ONs at the present have three-component accelerometer and pressure gauge as a tsunami-meter. A route for new OBCST is selected in consideration of those of the existing cable and plans for another new cable system, and a route survey was carried out in 2013.

There is only one landing station for the existing system. The OBCST system shares the landing station which is rebuilt for the existing system. Therefore the Ethernet channel is adopted to be turned at the seaward end of the cable. Because of introduction of the WDM for the OBCST system, only one fiber is needed for Ethernet communication. Since the seafloor cable has 6 optical fibers, four fibers are used for the Ethernet cannels and two fibers are employed for the clock module. The data transmission channel using the Ethernet is duplicated and both of the Ethernet channels are turned in the furthest ON from the landing station for ring configuration. The clock module also has duplicated channel for redundancy. The data from the ONs are transmitted to the landing station. At the landing station, the data are stored in a large disk array system. In addition, a part of the data from the ONs is transmitted to the ERI, the University of Tokyo in Tokyo and Data Center in Nagano for distribution. When a remarkable event occurs, all the data of the event can be retrieved via the Internet. The system control commands are sent from the ERI (Figure 3).

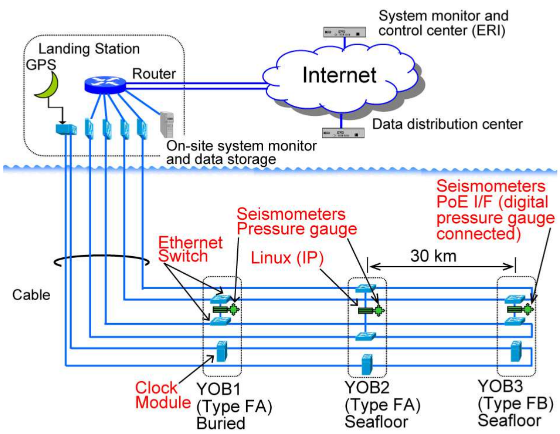

Figure3: Network of the OBCST system

Deployment of the OBCST system was carried out in September 2015 by using a commercial telecommunication cable ship. First, the cable ship swept the seafloor along the cable route to remove obstacles on the seafloor. Cable end was landed to the landing station and the cable ship started deployment of the cable system offshore. In the region where the water depth is less than 1,000 meters, the submarine cable and the ON closest to the coast (YOB1) were simultaneously buried with using a plough-type burial machine.

Burial depth is 1 meter below the seafloor. Finally, a remote operated vehicle (ROV) buried the submarine cable around the landing point (Figure 4). After finishing of the deployment, data recording was immediately started.

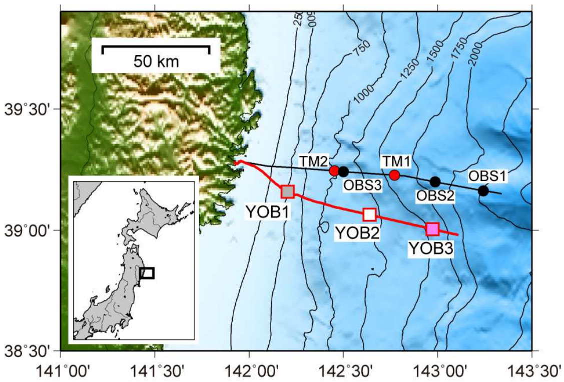

Figure 4: Position of the OBCST system

5. OBSERVATION DATA FROM OBCST SYSTEM

The seismic data from the OBCST system off Sanriku enable us to study the seismic noise in the frequency range from 10 mHz to 20 Hz. Spectrum of the ambient seismic noise is calculated with a time window of about two and half hundred seconds (Figure 5). It is found that the noise levels at the OBCST system are low at frequencies greater than 3 Hz and smaller than 0.1 Hz. This level of ambient seismic noise is close to a typical system noise. In addition, the noise levels at the OBCST system are comparable to those at the existing cabled system off Sanriku. The burial ON below the seafloor (YOB1) has low noise environment. It is known that burial of the sensor package is effective for seismological noise reduction [11]. Reflecting a low noise environment, s small earthquake was recorded clearly by the OBCST system (Figure 6)

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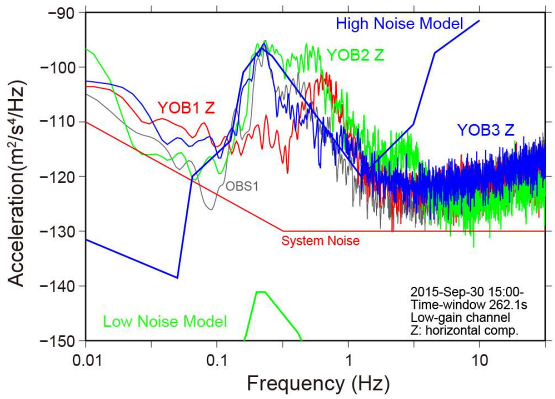

Figure 5: Noise spectra of the OBCST system

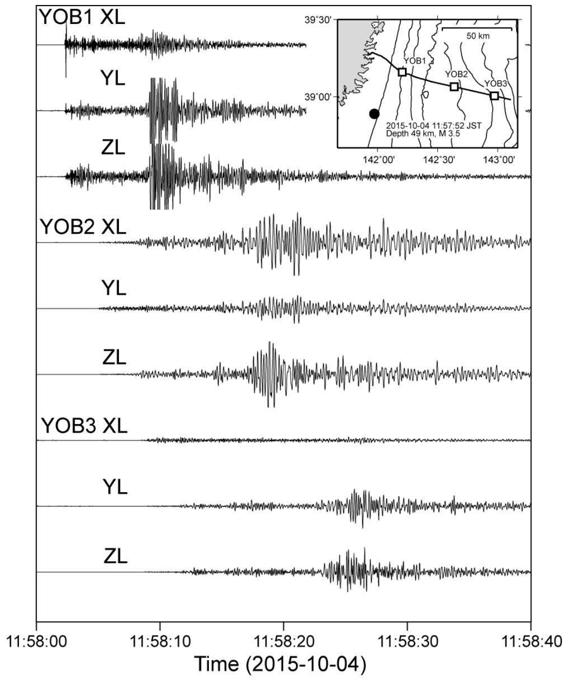

Figure 6: Earthquake records by the OBCST system

Water pressures are simultaneously observed by high-precision pressure gauges of both the OBCST system and the existing system. Because a crystal oscillator type pressure gauge is sensitive to temperature, the sensors also observe temperature. We found that temperature of the buried ON (YOB1) does not change. Other sensors on the seafloor have small variation of temperature which may be originated by change of sea water temperature near the seafloor. It is also found that a sensibility of pressure gauge which is buried does not have a large change comparing to that on the seafloor (Figure 7). From the data, pressure gauge has a resolution of less than 1 hPa, which corresponds to a change of water height of less than 1 cm, and data from all the sensors are consistent.

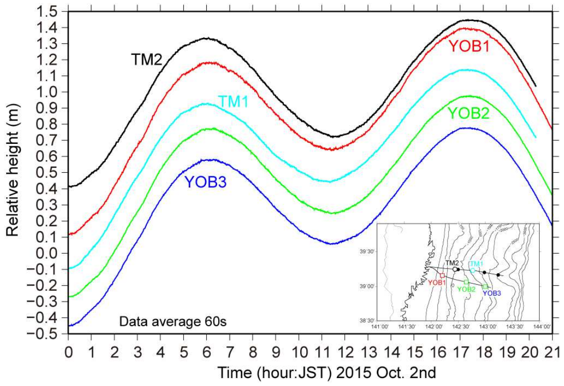

Figure 7: Records from pressure gause by the OBCST system and the existing system.

6. CONCLUSIONS

We developed a new OBCST and installed the system to the region off Tohoku district, northeastern Japan. Our system is characterized by the application of ICT technologies. By using the ICT, the system becomes compact and less expensive. IP access and an upgrade of software in the system are enabled.

The new OBCST is the second of the system which is based on the ICT, and has new features: Giga-bit Ethernet, IEEE1588, WDM, and PoE, etc. The OBCST has three-component seismometer and pressure gauge as scientific sensors. Instead of pressure gauge, PoE interface can be selected. Reliability of the system is kept by using redundant system which is easily constructed using the ITC. The ONs on the seafloor can be accessed through TCP/IP, and CPU and FPGAs are implemented into the ONs. This provides us an ability of changing measurement parameters of the sensors, and upgrading the firmware and software in the ONs.

In September 2015, we installed the system off Sanriku, northeastern Japan. In this region, we already installed a seismic and tsunami observation system using conventional technology in 1996. The objectives of the observation are to obtain exact seismic activity related to plate subduction such as the 2011 Tohoku earthquake and to observe tsunami on seafloor using two cable observation systems. The new system has a total length of 105 km and three ONs. Two ONs have a built-in tsunami sensor. Another has an external port. At the deployment of the system, we connected a tsunami gauge as an external sensor. The data from each ON are sent to our institute and data distribution center via a landing station using TCP/IP protocol. The data are also stored in the landing station.

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