Ocean-Bottom Seismographic Observation Systems

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Abstract

Since the first offshore installation at Omaezaki, Shizuoka-ken, in August 1978, a total of eight "cable-based" ocean-bottom seismographic observation systems (In-Line type systems) have been installed for use in the real-time observation of earthquake and tsunami data on the Pacific side of the Japanese Archipelago. These systems are applying a digital communication technology and a high reliable technology of the submarine cable system. On the other hand, development of the "NODE type system" featuring two dimensional observations by seismometer and tsunami sensors deployed planarly was started in the USA, Japan and European countries around the year 2000. This paper introduces the technologies applied to the earlier In-Line type systems as well as outlining the most advanced system technologies used in the currently deployed NODE type systems.

Keywords

sea-bottom seismographic observation, analog, digital, optical wavelength-division multiplexing optical bidirectional, in-line, node, two dimensions

1. Introduction

A total of eight submarine cable-based sea-bottom seismographic observation systems (In-Line type) are now operating in the sea areas that surround Japan. The first was the Omaezaki offshore permanent ocean-bottom seismographic observation system (coaxial analog transmission system), which was built in August 1979 by the Japan Meteorological Agency (JMA). The most recent was the Omaezaki offshore system (optical fiber digital transmission system) built in July 2008 also by JMA (**Fig. 1** , **Table 1**).

Since completion of the "East Izu Peninsula offshore seismographic system" built by the Earthquake Research Institute (ERI) of the University of Tokyo, in March 1993, the

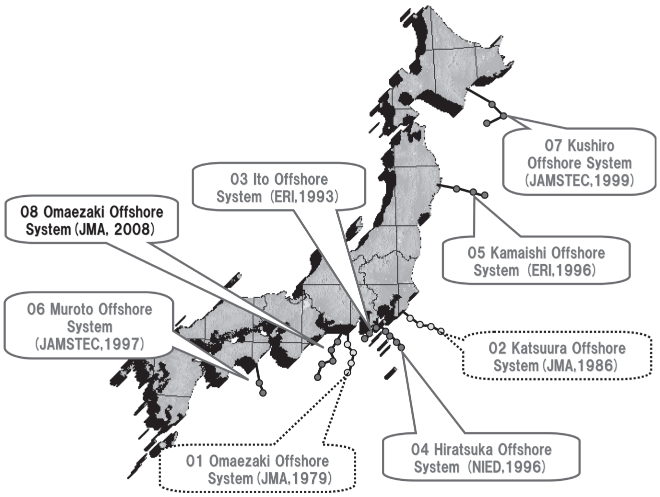

Fig. 1 Sea areas with seismographic observation systems.

Table 1 Installation locations and organizing authority.

No.	Location	Organizing Authority	Year	System Length
1	Omaezaki, Shizuoka Pref.	Japan Meteorological Agency (JMA)	1979	120 km
2	Katsuura, Chiba Pref.	JMA	1986	96 km
3	Ito, Shizuoka Pref.	Earthquake Research Institute (ERI), University of Tokyo	1993	28 km
4	Hiratsuka, Kanagawa Pref.	National Research Institute for Earth Science and Disaster Prevention (NIED)	1993	127 km
5	Kamaishi, Iwate Pref.	ERI	1996	123 km
6	Muroto, Kochi Pref.	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)	1997	125 km
7	Kushiro, Hokkaido Pref.	JAMSTEC	1999	242 km
8	Omaezaki, Shizuoka Pref.	JMA	2008	210 km

optical digital transmission method using optical fibers was adopted. This innovation made it possible to provide systems that can monitor sea-floor earthquakes with higher accuracy and a higher dynamic range and to transmit the data over long distances without degrading the resolution or accuracy.

On the other hand, the next generation system (NODE type system) development has begun in the USA, Japan and European countries, which aims to achieve dense observation. This system features a device called a "node", which is installed on the sea bottom and is connected to various observation sensors using an ROV (Remotely Operated Vehicle) and deploys a planar sensoring arrangement.

2. Cable-based Ocean-bottom Seismographic Observation System (In-Line Type System)

The "cable-based" ocean-bottom seismographic system is composed of ocean-bottom seismometers (**Photo 1**), tsunami sensors (**Photo 2**) and terminal equipment (**Photo 3**). The location and number of ocean-bottom seismometers and tsunami sensors are determined according to the purpose of the research (observation) of the organization installing the system. **Fig. 2** shows a system block diagram of a typical "cable-based" ocean-bottom seismographic observation system (Omaezaki Offshore System of JMA).

In Table 1, the ocean-bottom seismographic observation systems from No.3 offshore Ito, Shizuoka Prefecture, of the ERI, University of Tokyo, to No. 8 offshore Omaezaki of JMA are the new-generation systems based on digital data transmission. This system was released in order to enhance the seismic observation ability around the system deployment area together with past analog system. These digital-transmission ocean-bottom seismographic observation systems apply the optical digital transmission technology adopted in the

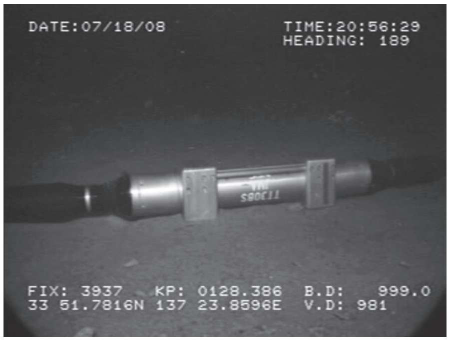

Photo 1 Ocean-bottom seismometer (JMA).

Photo 2 Tsunami sensor (NIED).

Photo 3 Terminal equipment (JMA).

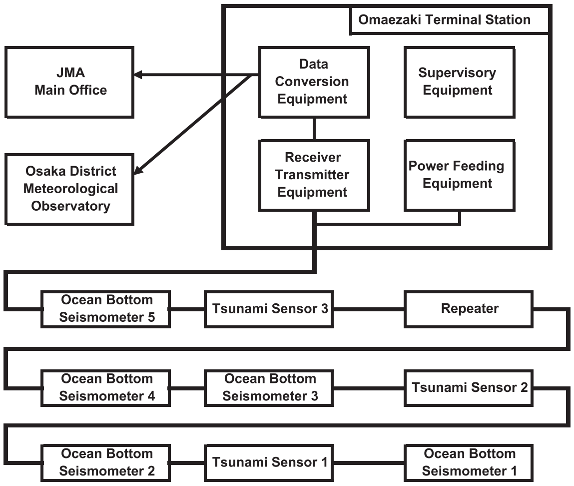

Fig. 2 Block diagram of ocean-bottom seismographic observation system (JMA).

submarine cable communication systems. The analog data from the “ocean-bottom seismographs” and “tsunami (water pressure) gauges” connected to the submarine cable is converted into digital data (A/D conversion). The signal is then converted from electrical to optical (E/O conversion), and the optical signal is transmitted in real time to the terminal equipment at the terminal station via optical fibers. As shown in Table 1, a total of six digital-transmission ocean-bottom seismographic observation systems were built in the sea areas surrounding Japan between 1994 and 2008. The data and control transmission methods of each system were established as described below. **Table 2** shows the features of each system.

The earthquake and tsunami analog data observed by the ocean-bottom seismographic observation systems are converted into 16-bit or 24-bit digital data by means of 1 kHz or 8 kHz sampling rates, and the optical signal obtained from the digital data is transmitted in real time to the terminal equipment of the land station. With systems Nos. 1 to 3 and No. 6 in Table 2, the data measured with the ocean-bottom seismometers and tsunami sensors is transmitted to the land station by allocating single optical fiber to each seismometer and tsunami sensor (1:1 relationship between sensors:fibers). However, with systems Nos. 4 and 5, it was impossible to maintain the 1:1 relationship because the number of sensors exceeded the number of optical fibers. These systems therefore use other technologies such as optical wavelength-division multiplexing and optical bidirectional transmission.

Table 2 Features of digital-transmission ocean-bottom seismographic observation systems.

No.	Wavelength band	System clock	Main observation data	Optical amp	Optical wavelength division multiplexing	Optical bidirectional transmission
1	1.3 µm	Master async., 1.544 MHz	16-bit A/D, 8 kHz sampling	—	—	—
2	1.5 µm	High-accuracy sync, 1.544 MHz	16-bit A/D, 8 kHz sampling	Land: 1	—	—
3	1.5 µm	High-accuracy sync, 1.544 MHz	16-bit A/D, 8 kHz sampling	Land: 1	—	—
4	1.5 µm	High-accuracy sync, 1.544 MHz	16-bit A/D, 8 kHz sampling	Land: 1 Submarine: 1	2 wavelengths	—
5	1.5 µm	High-accuracy sync, 8.192 MHz	24-bit A/D, 1 kHz sampling	Land: 1 Submarine: 6	2 wavelengths, 3 wavelengths	Applied
6	1.5 µm	High-accuracy sync, 8.192 MHz	24-bit A/D, 1 kHz sampling	Land: 1 Submarine: 4	—	—

2.1 Application of Optical Wavelength–division Multiplexed Transmission and Optical Bidirectional Transmission

System No. 7 in Table 1, Long-Term Deep Sea Floor Observatory off Kushiro in Hokkaido Prefecture (**Fig. 3**) is a cable type system. It comprises three ocean-bottom seismometers (Photo 1), two tsunami (water pressure gauges) sensors (Photo 2), one set of Deep Sea Observatory incorporating various submarine observation sensors and two branching MUX units connecting submarine observation devices. These are connected to a 240-km long optical submarine cable with six optical fiber conductors to transmit the observation data in real time to the terminal equipment installed in the land station (Photo 3).

One of the six optical fibers is assigned for the clock from the land station equipment (Photo 4) to the “submarine observation equipment” and the control signal from the terminal station equipment to the Deep Sea Observatory. Four optical fibers are assigned for an individual observation of the submarine seismographs, tsunami (water pressure gauges) sensor and Deep Sea Observatory, and the last optical fibers is assigned to the branching MUX signal line.

Of the four optical fibers assigned for individual observations, one is dedicated for the image data from the deep sea

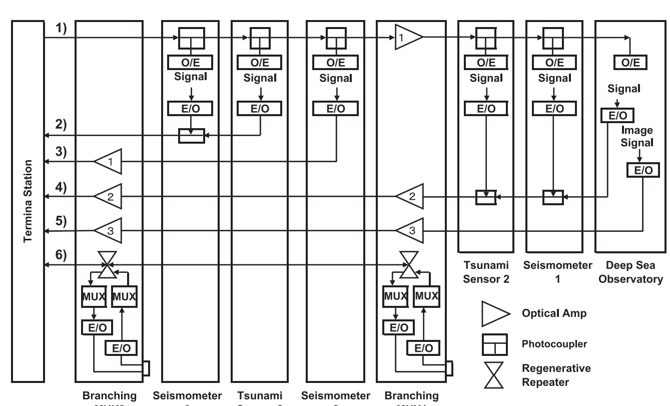

Fig. 3 Block diagram of Long-Term Deep Sea Floor Observatory off Kushiro system.

camera in the Deep Sea Observatory and the other optical fibers are used to transmit data from three ocean-bottom seismometers, two tsunami (water pressure gauge) sensors and one set of Deep Sea Observatory (total 6 units) to the terminal station. This system transmits by applying optical wavelength-division multiplexing and optical bidirectional transmission methods.

2.2 Application of Optical Wavelength–division Multiplexed Transmission

By applying wavelength-division multiplexing technology, the data from six units is transmitted to the land station via three optical fibers. To be precise optical fiber 2) is used to transmit the data of two pieces of submarine observation equipment by two-wavelength multiplexing of the “Seismometer 3” data and “Tsunami gauge 2” data at Seismometer 3. Meanwhile, optical fiber 3) is used to transmit the data of three pieces of equipment to the land station by multiplexing the “Deep Sea Observatory” data and “Seismometer 1” data at Seismometer 1, and then multiplexing the “Tsunami sensor 1” data with the multiplexed data (total three wavelengths) at the Tsunami sensor 1. Furthermore, to compensate for data transmission losses, optical direct amplification (Optical Amp) at two locations within the transmission path (repeaters inside the branching MUX units) is applying.

2.3 Application of Optical Bidirectional Transmission

Initially, the branching MUX units are installed on the surface of the seabed without connecting any observation sensors. The units are equipped with analog and serial signal multiplexing functions so that equipment such as ocean-bottom seismometers and other maritime observation sensors can be connected for the real-time acquisition of observation data. One of their features to be noted is that they apply the optical bidirectional transmission technology. When transmitting the observed data of various sensors including ocean-bottom seismometers, it is required to send sensor control signals to the sensors from the terminal station. However, there is only one optical fiber assigned to the branching MUX units. Therefore, the optical bidirectional transmission method is adopted by splitting the optical fiber transmission paths using photocouplers, so that the control signals from the terminal equipment to the sensors and the observation data from the sensors to the terminal equipment may each be transmitted via a single optical fiber.

3. Node Based System

The “cable-based” ocean-bottom seismographic observation system is an “in-line system” by which ocean-bottom seismometers, tsunami sensors and other sensors are connected to a submarine cable. Applying the high reliability technology of submarine cable systems, the system has been able to boast fail-free achievements over more than three decades and is still continuing to provide real-time observation data.

On the other hand, there is next generation system that connects “NODE” (observation relay equipment equipped with ports (interfaces) accepting connection of multiple seismometers, tsunami sensors and other environment sensors) to a submarine communication cable. This system enables observation of complex geophysical activities (earthquakes, tsunamis) and maritime environmental changes (in tidal currents, seawater temperature and seawater constituents) over a broad area. It began to be developed in the USA, Japan and European countries in the year 2000. The main projects currently underway include the NEPTUNE (North-East Pacific Time-series Undersea Network Experiments) led by the Washington University in the USA and the ESONET (European Seafloor Observatory Network) in Europe, and actual observations have already started in parts of these systems.

In Japan, JAMSTEC has started the DONET (Dense Ocean-floor Network System for Earthquakes and Tsunamis) program to promote construction of a system that has three aims; 1) a contribution to disaster prevention and reduction; 2) advancement of earthquake prediction models; 3) development of the world’s most advanced technologies.

The first ocean-floor network system will be constructed in the Kumano-nada sea area (To-Nankai region offshore Kii Peninsula, Mie Prefecture) where large scale earthquakes are occurring at an interval of about 150 years. It is scheduled to be completed by the end of March 2010, after which the actual dense observations will be started (**Fig. 4**).

The system is composed of a backbone cable system with a length of about 300 km (application of submarine communication technology), five NODEs, twenty instrument sets and terminal station facilities. The twenty instrument sets include a broad-band seismometer, a strong-motion seismometer, a water pressure gauge and a temperature sensor, etc. These sets will be installed densely in those parts of the Kumano-nada sea area with a high probability of an occurrence of large scale earthquakes in near future in order to contribute to the prevention and reduction of disasters by detecting in real time any

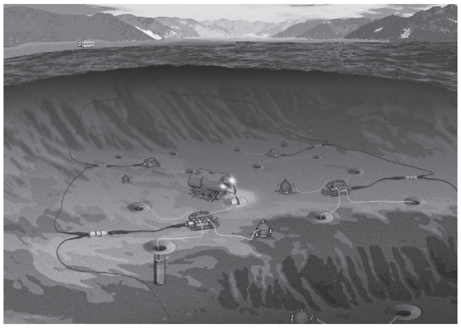
Fig. 4 Image of DONET (Source: JAMSTEC website).

small scale crustal activities before an earthquake occurrence. They will also help elucidate the mechanisms of such earthquake occurrences and will enable their simulation.

NEC began to be engaged in the implementation of this system in FY2007. After the system design and prototyping/evaluation of equipment that applied the world's most advanced technologies, we are now entering the final stage of equipment manufacturing aiming at the actual laying of the system by the end of FY2010.

The installation of the system begins with the ocean-floor laying operation for the backbone cable system, using a commercial submarine cable laying ship. After this, five NODEs will be deployed using the ROV owned by JAMSTEC and these will be connected to the backbone cable system via underwater connectors. To follow on twenty instrument sets will be laid on the surface of the ocean floor using the same ROV and these will be connected to the nodes via underwater connectors, and put to a real-time observation service.

The NODEs and instrument sets can be laid at desired locations by using the ROV, which may also be used in the future maintenance of the observation instruments. This system is capable of functions that have been previously impossible with the in-line type systems, including; 1) system extension; 2) displacement of observation instruments; 3) replacement of observation instruments.

In order to improve the accuracy of the simulation analyses of the large scale earthquakes to which occurrence is feared in the future, the timestamp of the acquired data is given an accuracy of 1 μsec, which is highest among the submarine observation systems worldwide.

4. Conclusion

Since the construction of Japan's first cable-based ocean-bottom seismographic observation system was completed offshore Omaezaki for JMA in 1979, NEC has supplied and commissioned all of the eight ocean-bottom seismographic observation systems that operate in the sea areas around Japan. Currently, under the guidance of the participating research institutions, governmental ministries and agencies, we are tackling the prototyping/evaluation/implementation of DONET, a state of the art NODE-based system.

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