A Technical Report on the Advanced Real-time Earth Monitoring Network in the Area (ARENA)

Chapter 1: Preface

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Contents

1.1 Introduction

As the ocean floor is covered by huge amounts of seawater, it is not easy to have a close observation and understanding of it. Nevertheless, recent advances in science and technology have revealed that the ocean and ocean floor have a major impact on human society and life. A typical example is earthquakes. It is known that gigantic earthquakes occur periodically near plate boundaries. To elucidate the generation mechanism of these earthquakes and minimize the damage caused by them, it is necessary to step up monitoring by deploying large numbers of observation instruments on the ocean floor near the seismic zone.

It is also known that the ocean has a major impact on climatic change, but the role which deep-sea water plays in the global climate is not fully understood. To advance such research, it is important to measure the long-term changes in the deep ocean-floor environment and interaction between seawater and the earth's crust involving heat and material. Moreover, peculiar organisms, such as those which survive on chemical synthesis involving hydrogen sulfide, have been observed on the deep ocean floor, and this has made it a major research focus in terms of its link to ancient life forms. One of the important research themes relating to the elucidation of the real nature of the earth is the probing of the structure of the earth's interior using ocean-floor boreholes, seismic tomography, electromagnetic tomography, and the like.

As a means of conducting deep-sea observations, submarine cables have been playing an important role. As will be discussed in the next section, submarine cable-based seismic monitoring in Japan began in the 1970s, and eight scientific submarine cables have already been constructed(1) (see **Figure 1-1**). As part of this process, new construction techniques, including the installation of a large number of observation instruments around an ocean-floor junction box using an underwater mateable connector and the use of an extension cable to deploy a mobile observation system at locations up to 10 km from the backbone cable, have been put to practical use.

Alongside this, related technologies, such as optical submarine cable technology, data communication & processing technology, semiconductor technology and positioning technology (e.g. GPS), have made rapid progress. Such technological innovations are expected to have major implications for scientific submarine cable networks. For example, it has become a reality to build a flexible communications network

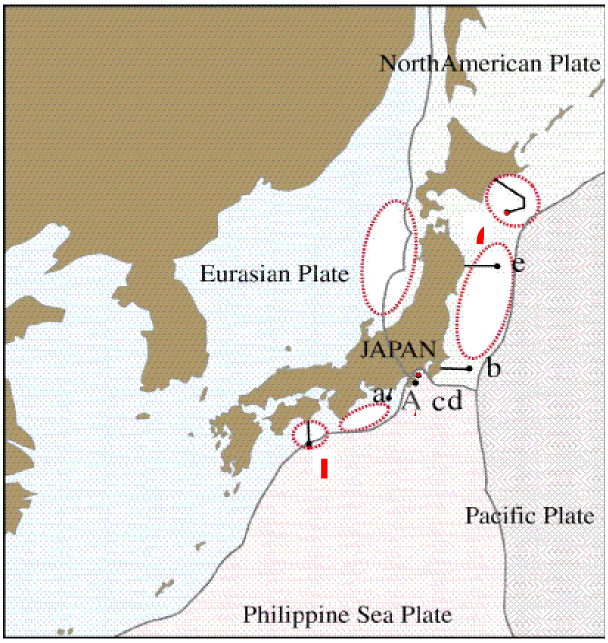

Figure 1-1 Eight Seismic Monitoring and Experimental Submarine Cable-Based Observation Systems in Japan

a) Japan Meteorological Agency (JMA) : Off Suruga; b) JMA: Off Boso; c) Earthquake Research Institute, University of Tokyo (ERI): Off Izu Peninsula; d) National Research Institute for Earth Science and Disaster Prevention: Sagami Trough; e) ERI: Off Sanriku; A) Japan Marine Science and Technology Center (JAMSTEC): Off Hatsushima (experimental); B) JAMSTEC: Off Muroto; and C) JAMSTEC: Off Tokachi-Kushiro. The areas marked off with a red line represent sea areas designated for stepped-up seismic monitoring.

connecting sensors and laboratories through the use of Ethernet and other communications technologies. Similarly, the latest optical submarine cable technology(2) based on optical amplification and wavelength division multiplexing has made it possible to build a flexible submarine cable network. Let us now have a brief historical overview of optical submarine cable communications technology, which is a related technology of particular significance.

Although the transatlantic optical submarine cable that was put to commercial use in 1988 as a world first had a data transmission capacity of only 280 Mbps per fiber, this was expanded to 960 Gbps per fiber, an approx. 3400-fold increase, 13 years later in 2001. While the regenerative repeater (a repeater in which attenuated optical signals are amplified and waveform-shaped after being converted into electronic signals and then retransmitted after being converted back into optical signals) was used in first generation optical submarine cables, the optical amplification system, in which optical signals are directly amplified, made its debut in 1994, followed by the practical application of the wavelength division multiplexing technique, in which optical signals with multiple wavelengths travel in a single fiber. Wavelength division multiplexing is combined with optical amplification.

In the optical amplification scheme, transmitted signals are bit-rate-free. This means that diverse terminal equipment can be used, making it possible to implement a low-cost data transmission system according to the intended purpose. The use of wavelength division multiplexing, on the other hand, facilitates signal branching and the introduction of additional transmission channels. Together, these advances in optical submarine cable communications technology have made it much easier to build low-cost flexible data transmission systems.

Overall, advances in related technologies have paved the way for the implementation of scientific submarine cable networks with new functions and configurations. Just as advances in semiconductor, optical communications and telecommunications technologies have brought about an information revolution in modern society, advances in the above related technologies have the potential to bring new knowledge to deep-sea research and give rise to new sciences.

Against this background, the IEEE Oceanic Engineering Society Japan Chapter set up the Technical Committee on Globe Monitoring Cable Network to conduct a technical study on a next-generation scientific submarine cable network and put together proposals. The proposed scientific submarine cable network was named the Advanced Real-time Earth monitoring Network in the Area (ARENA).

Since its establishment on February 14, 2002, the committee has met a cumulative total of ten times through its three working groups - the Power Feeding System Working Group, the Data Transmission System Working Group and the Underwater System Working Group - to address the practical aspects of the network. A total of 47 persons took part in those meetings. The findings of these working groups are compiled in Chapter 3 “Power Feeding System”, Chapter 4 “Data Transmission System” and Chapter 5 “Underwater System”. Chapter 2 “A Network Overview” summarizes issues that form the basis of the discussions of later chapters, including technical requirements, the network model, power consumption, amount of data and synchronization accuracy, as well as the conceptual image. Hereafter, this chapter will briefly describe the present state of scientific submarine cables in Japan (**Section 1.2**), introduce some results using existing submarine cable-based seismometers (**Section 1.3**), examine the advantages of networking (**Section 1.4**) and summarize the expected application areas of scientific submarine cable networks (**Section 1.5**).

1.2 Present state of scientific submarine cables in Japan

(1) Scientific submarine cables for seismic-monitoring

In Japan, submarine cable-based seismic monitoring began in the second half of the 1970s as part of the nation’s earthquake preparedness efforts. In 1996, the Headquarters for Earthquake Research Promotion recommended the installation of submarine cable-based seismic observation systems in five sea areas to step up seismic monitoring. As shown in **Figure 1-1** (p. 1), eight scientific submarine cables have so far been constructed in Japan - two by the Japan Meteorological Agency (JMA), two by the Earthquake Research Institute, University of Tokyo (ERI), one by the National Research Institute for Earth Science and Disaster Prevention (NIED) and three by the Japan Marine Science and Technology Center (JAMSTEC).

(2) Experimental system utilizing underwater telecommunication cable: VENUS Project

While all scientific submarine cables shown in **Figure 1-1** have been constructed specifically for scientific purposes, retired underwater telecommunication cables can also be used for scientific observation. The use of retired underwater telecommunication communications cables not only makes a low-cost implementation of scientific submarine cable systems possible, but also allows the recycling of submarine cable resources as precious assets of humankind as a whole.

Typical examples of the utilization of a submarine communications cable are the GEO-TOC cable[3] and the Okinawa-Guam submarine cable shown in **Figure 1-2**. In 1999, a junction box designed to hook up multiple observation instruments was connected to the Okinawa-Guam submarine cable on an experimental basis using science and technology promotion and coordination funds from the Science and Technology Agency[4]. The connected instruments included a broadband seismometer, tsunami gauge, hydrophone array, precision range meter for crustal movement observation, ad-hoc observation system, potentiometer, magnetometer and television camera. These instruments were connected to the junction box via an underwater mateable connector (**Figure 1-3**). This arrangement allows the maintenance of instruments via an ROV and future upgrading of sensors to those with new functions. The VENUS system enabled the continuous acquisition of observation data from sensors installed on the ocean floor until a breakdown of communication caused by the failure of underwater connector on the junction box.

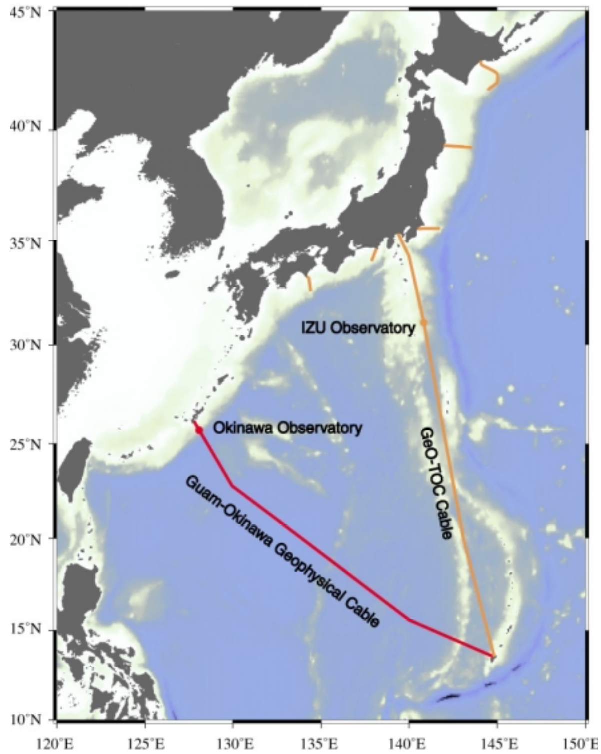

Figure 1-2 Reuse of Submarine Communications Cables in Japan

In Japan, two retired coaxial submarine communications cables are being utilized for scientific observation. Under the VENUS Project, a multipurpose observation station was experimentally attached to the former Trans-Pacific Cable 2 (TPC-2), which connects Okinawa and Guam. In addition, it is planned to insert sensors into the GEO-TOC cable (former TPC-1), which connects Ninomiya and Guam.

Slightly earlier than VENUS, a similar observation station was constructed to a submarine communications cable connecting Hawaii and California. These experiments demonstrated the feasibility of the installation of multipurpose ocean floor observation systems as well as the potential of submarine cable systems to become important sea floor observation infrastructure.

(3) Mobile observation system

Through the use of an 8-km extension cable, a mobile observation system[(6),(7)] was successfully deployed at a long distance from a Branch-MUX inserted into the Off-Kushiro-Tokachi observation system[(5)], which was installed in 2001. **Figure 1-4** shows an artist's view of the Off-Kushiro-Tokachi observation system. The laying and connection of the extension cable was undertaken using a deep tow and an ROV. This technique has not only increased the degree of freedom in the deployment location of observation equipment but also made it possible to deploy it at the desired location more accurately. It has also enabled the deployment of multiple sets of observation equipment on a two-dimensional basis. The extension cable used in this system only featured optical fibers. The development of an extension cable carrying a power feeder is the next step.

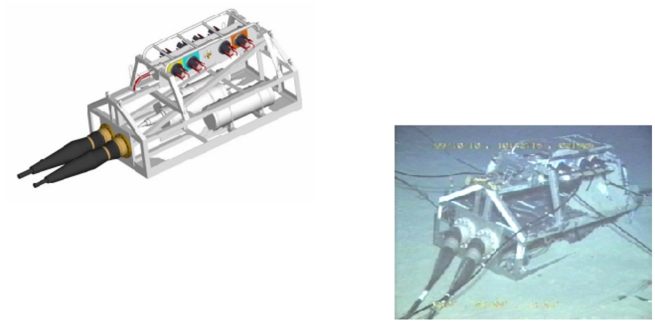

Figure 1-3　A junction box developed in the VENUS project.

The junction box provides electric power and data transmission line to multiple sensors including wide-band seismometer, tsunami sensor, geomagnetic and electric field observation system, hydrophone arrays, seafloor acoustic ranging system and television camera.

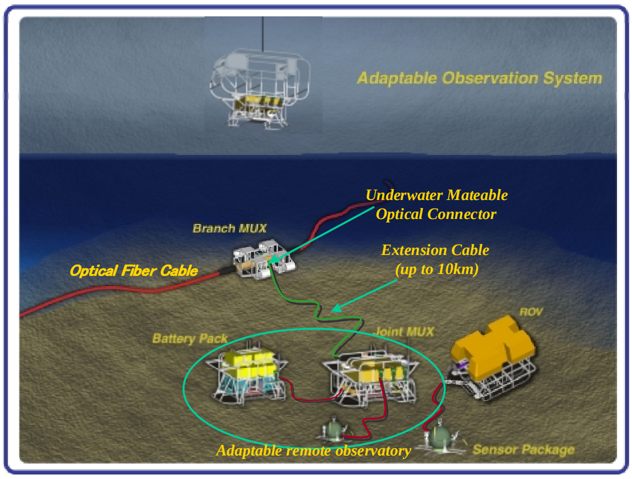

Figure 1-4　Off-Kushiro-Tokachi Observation System

With the Off-Kushiro-Tokachi observation system, a mobile observation system was deployed at a point 8 km from the backbone cable using an extension cable.

1.3　Achievements made in seismological field to date

As has been discussed above, the hypocenters of earthquakes that occur near a plate boundary are located beneath the ocean floor. For this reason, the deployment of observation equipment on the ocean floor near their hypocentral regions enhances both the sensitivity and accuracy of observation. **Figure 1-5** demonstrates the improvements in hypocenter locating accuracy achieved through observation using cable-based seismometers deployed off Muroto[(8)]. **Figure 1-6** shows the distribution of tremors captured by the Off-Kushiro-Tokachi observation system over a year-long period following its deployment. Many of these tremors could not be detected by land-based observation equipment. The installation of tsunami gauges alongside the seismometers made it possible to detect tsunamis and record pressure changes as well. These improvements in observation accuracy have opened up the way for a more detailed analysis of the earthquake generation mechanism.

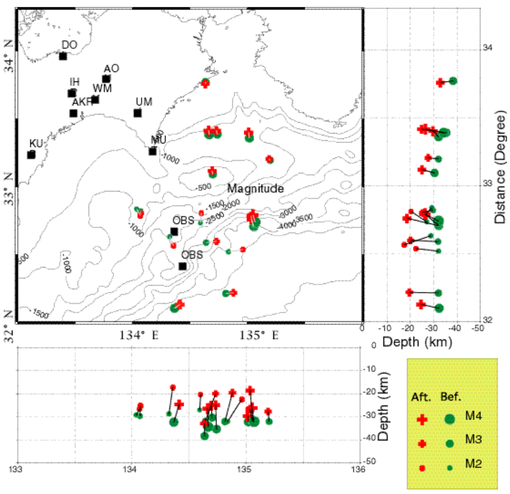

Figure 1-5　Improvements in Hypocenter Locating Accuracy

The map shows the estimated positions and depths of hypocenters. North-south and east-west vertical projections of the area are shown below and to the right of the map, respectively. The symbols “+” and “●” represent the estimated hypocenter locations obtained before and after the introduction of cable-based seismometers, respectively. The map demonstrates that the introduction of the cable-based seismometers has brought about improvements in hypocenter estimation accuracy.

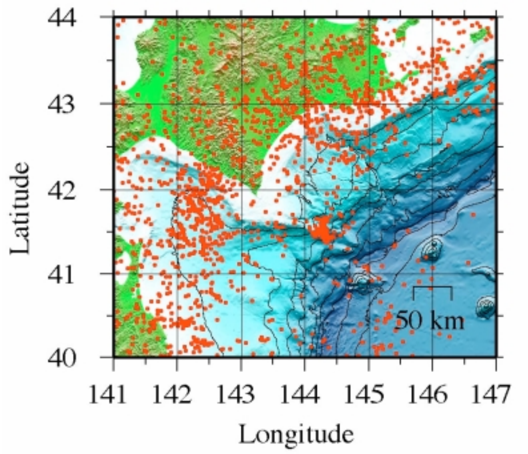

Figure 1-6　Distribution of Tremors captured by Off-Kushiro-Tokachi Observation System over Year-long Period following its Deployment

Many of these tremors could not be detected by land-based observation equipment.

1.4 Advantages of networking

Networking is believed to have the following advantages: (1) improvement of system redundancy and reliability; (2) improvement of system expandability; and (3) reduction of construction costs.

The sea surrounding the Japanese archipelago contains rich fishing grounds. Most faults occurring in submarine communications cables relate to fishing activities (see **Figure 1-7**). To avoid hindering fishing activities and prevent accidents involving fishing vessels, submarine Artificial cause usually laid under the ocean floor except for regions with depths of 1000-2000 m or more. Despite these efforts, however, it is not possible to completely eliminate problems associated with fishing activities. In existing scientific cable systems, a single cable connects a string of undersea observation equipment to the landing station one-dimensionally, so that any fault occurring in the cable disrupts observation beyond the location of the fault.

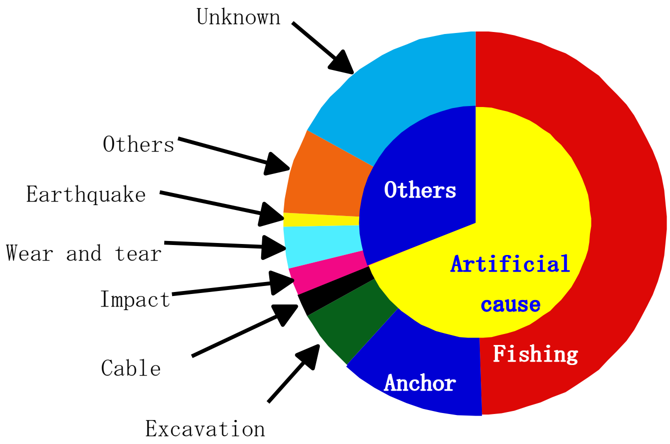

Figure 1-7 Causes of Faults occurring in underwater telecommunications cables

Source: International Cable Protection Committee (ICPC)

To be able to better handle faults, it is necessary to configure a cable system in such a way that it forms a network featuring mesh-like architecture with multiple landing stations. This arrangement would give the system the necessary redundancy to ensure continued data transmission in the event of the occurrence of a fault at one location.

Another advantage of networking is expandability. Earthquakes occurring around Japan are distributed widely along the plate boundary, which runs parallel to the Japanese archipelago. In addition to land observation points having been established at 15-20 km grid intervals, it is desirable to establish observation points at 20-50 km grid intervals over the ocean to expand the observation network that covers the Japanese archipelago to include the surrounding seas. The construction of such a large-scale scientific cable is expected to take place step by step through a series of expansions, rather than being carried out in one stroke. For this reason, it is desirable that the backbone cable system itself be configured to be expandable on a block by block basis, with both the cable and data transmission system given an ample capacity margin by accurately estimating the final capacity requirements.

The third advantage is cost reduction through the manufacturing of equipment according to common standards. Undersea equipment is expensive to construct and repair since it needs the support of a mother ship equipped with sophisticated facilities. Moreover, a mother ship requires more than several months of preparation before it can set sail, so that the occurrence of a fault in observation equipment cannot be dealt with straightaway, resulting in a prolonged loss of measurement data. To avoid this problem, undersea equipment must have high reliability, but high reliability requires extensive reliability tests during development, leading to high development costs. Enhanced redundancy provided by networking, however, relaxes reliability requirements for undersea equipment, and, along with the adoption of common standards, helps lower its unit costs.

1.5 Expected application areas

In this section, non-seismological application areas are discussed.

(1) Marine environment study

Although it is well-known that the ocean has a major impact on the global environment, its detailed mechanism is not yet understood. To shed more light on this matter, it is necessary to undertake research in various areas, including the thermal and material cycles of the ocean, temperature changes in it and the interaction between the solid earth, the ocean and the sky. Scientific submarine cable networks provide the basic data necessary for such research.

(2) Seismic probing of earth's interior

The resolution of the seismic probing of the earth's interior depends on the average deployment density of seismometers. A poor resolution of about 2000 km for sea areas is attributable to the low number of undersea seismometers that have been deployed. In this regard, submarine cable-based earthquake monitoring systems are expected to significantly boost the probing resolution. Seismic tomography covering regions close to the surface is one of the most interesting application areas.

(3) Electromagnetic probing of earth's interior

The measurement of electromagnetic fields over the ocean floor is used for exploring the inner structure of the earth. These constitute important application areas for submarine cable-base observation systems.

(4) Application to deep-sea biology

The deep sea harbors unique life forms not seen elsewhere. These include giant white clam which not only survives under high-pressure conditions but also lives symbiotically with bacteria that turn hydrogen sulfide seeping out of the ocean floor into nutrients. Since it is not easy to raise deep-sea organisms on land and study their ecology, hopes are pinned on long-term biological experiments and observations conducted in the deep sea. In concrete terms, this will involve the use of a remotely controlled robot connected to a scientific submarine cable system.

(5) Other application areas

It is expected that scientific submarine cable systems will be used in many other areas, including the long-term observation of methane hydrates and other seabed resources, monitoring of the marine environment in relation to deep-sea sequestration of CO_2, an idea being proposed in some quarters, and the monitoring of undersea volcanic activity.

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