SEISMIC OBSERVATION SYSTEMS
UTILIZING SIGNIFICANT TELECOMMUNICATION TECHNOLOGY IN JAPAN

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Abstract: The Japanese Islands have suffered from disastrous earthquakes over their entire history. In order to deal with this phenomenon, we have developed the Seismic Observation System. Presently there are 7 Seismic Observation Cable systems in the ocean around the Japanese Islands. This sensing system, based on the Ocean Bottom Seismometer, improves earthquake observation accuracy, provides early warning to prevent expected damage, and enables the continuous study of earthquake mechanisms. The first stage of this system used Analog data transmission to transfer the observed seismic data, but was later followed by Digital data transmission. All systems developed by us are in use today and have been fully functional with no failures over their lifetimes. Enhancement of the observation network and real-time data exchange has made a great contribution to disaster mitigation in Japan. We presently have a new, large ongoing project called "TONANNKAI" using the latest and most advanced technology.

1 INTRODUCTION

At the end of 2006, a devastating earthquake occurred near southern Taiwan, damaging several Submarine Telecommunication Cable Systems located around the Taiwan Islands, causing unexpected and huge confusion to the human economic activities throughout the Asian region. Similarly, there is a possibility of a similar disaster in and around the Japanese Islands in the near future due to the fact that the Japanese Islands are located in one of the most active earthquake areas in the world, in the view of geophysics and geotectonic.

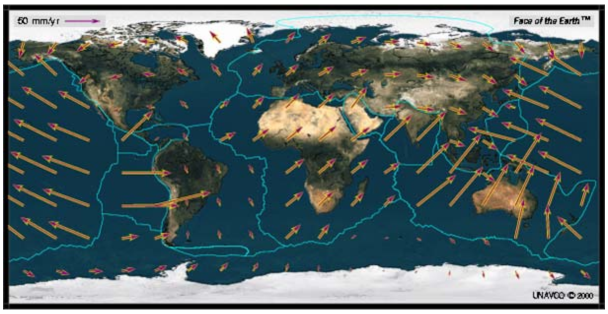

Fig1-PLATE tectonics in the world

The Japanese Islands are located on a subduction zone between continental and oceanic plates.（Fig.1） Figure 2 clearly shows that the Japanese Islands are one of the most active areas for earthquake occurrences in the world. (Fig.2) Seismologists have pointed out the necessity of deployment of Earthquake Observation systems in the ocean area where huge earthquakes may occur in the near future. As a result, thousands of seismometers have been manufactured and deployed on the Japanese islands by seismic laboratories founded by the government and universities. Japan has become the leading country in the field of Seismic Observation.

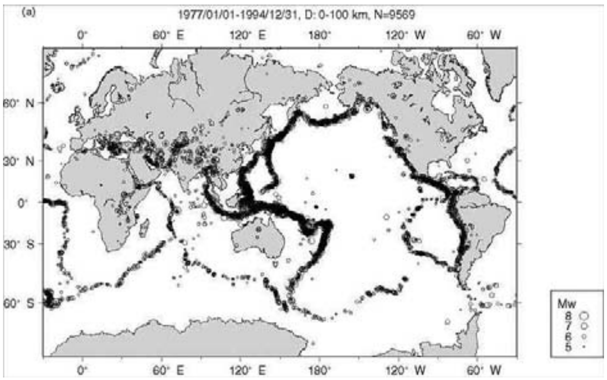

Fig2 Earthquake distribution

7(seven) Submarine Cable Seismic and Tsunami Monitoring Systems, consisting of over 20 km of submarine cables, have been deployed around the Japanese Islands during the last three decades. (Fig.3) The first was established in 1979. It was operated by FM-FDM (Analog) method in 1979 and kept progress of the system to Digital 16 bit (Optical) in the next stage in 1993, then Duplex Communication, Optical Amplifier in 1996, WDM in 1997, Digital 24 bit, and Multi-Sensor System in 1999.

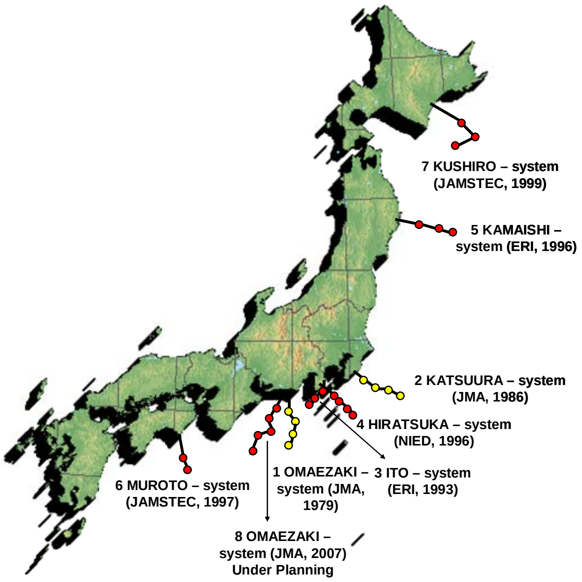

Fig3 Seismic observation cable systems locations

We have made significant improvement on the system's technology in the last three decades. Presently these systems can supply earthquake occurrence information to Japan's Urgent Warning System on a real-time basis, and all of the 7 Seismic Observation Systems deployed are working still and have been fully functioning without any failures over their lifetimes. We have continued to enhance the earthquake observation sensors' sensitivity to provide more accurate information and allow for the detailed study of earthquake occurrence mechanisms.

We believe that our mission is to provide the Seismic Observation Systems with high performance and accuracy to help minimize the damage from earthquakes and the tsunamis following earthquakes.

This paper first describes the geographic characteristics of earthquakes in Japan, followed by an explanation of Seismic Observation Cable Systems with a road map of their development, and ends with an introduction of our ongoing project of the new Seismic Observation system.

2 THE GEOGRAPHIC CHARACTERISTICS AND EARTHQUAKES

The Japan Trench is located between 4 main plates, the Pacific plate, the North American plate, the Philippine Sea plate, and the Eurasia plate, all of which are moving and colliding with each other. (Fig.4) The Pacific plate is subducting under the North American plate, and the Philippine Sea plate is subducting beneath the Eurasia plate in the Nankai Trough, where earthquake swarms occur. For example, the Pacific Plate is subducting under Hokkaido at a rate of 8 cm per year, heading west by northwest from the Chishima Trench. The collision of plates moving toward each other is the main cause of the Trench Type Earthquakes.

Due to the active diastrophism in line with such movement, there have been major earthquakes, such as the Tokachi Offshore Earthquake in 1952, which occurred in offshore waters on the pacific side of Hokkaido.

Fig4-PLATES around Japan Islands

Because of these geographic reasons, destructive earthquakes occur very often in Japan. While the area of Japan (380,000 square kilometers) is 1/30 the size of the United States, and doesn't even come up to 0.3% of the world (133.94 million square kilometers), the generation frequency of earthquakes exceeding magnitude 6 reaches about 20% of the entire world's rate.

Trench Type Earthquakes have been recorded to occur in a cycle of every 100 to 150 years in the area called the "TOKAI area", which includes these three areas: TOKAI, TONANKAI, and NANKAI. (Fig5) An earthquake, especially in a big city, could become disaster and bring about huge disruption by cutting off the telecommunication system. In the TOKAI area, which is close to the Tokyo Metropolitan area, a dense, high performance integrated Seismic Observation system has been installed like a mesh on the ground. This system detects crustal movement and other phenomena as might occur prior to earthquakes, in order to provide early warning in real-time to the capital city so that social infrastructure such as electricity, water, and gas, as well as telecommunication systems, will not be disrupted.

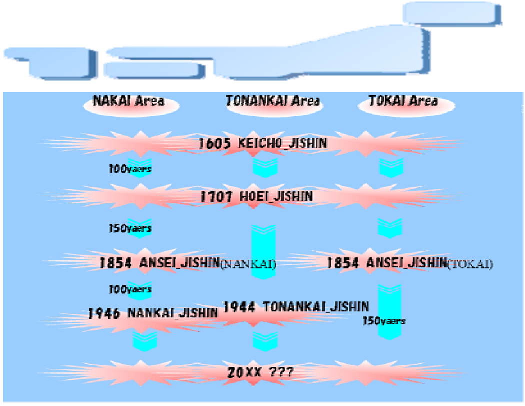

Fig5 Earthquake records of the last four centuries (Note: JISHIN means earthquake in Japanese.)

Seismic Observation Systems

Deployment of the Seismic Observation System

Firstly, the Marine Automatic Pop-up type Seismic Observation System was developed at the early stage. (Fig6) However, it was not useful to the area where earthquakes occur often because it took a while to collect data by using an off-line system, which made it difficult to control and operate the system from land stations which were located far from the seismic center.

Fig6 Pop-up type seismometers

To solve this problem, the New Seismic Observation Cable System was deployed to transmit Real-Time earthquake information prior to a major earthquake-induced ground motion. Up until now, all of the 7 Seismic Observation Cable Systems on the seabed around Japan have been fully functioning without any malfunction. We have been dedicated to the development and manufacturing of all the systems, and have contributed significantly to the improvement of the system's performance and accuracy. (Fig 7)

Fig7 We provide turnkey systems.

3 THE BASIC INFRASTRUCTURE OF THE SEISMIC OBSERVATION CABLE SYSTEM

The Cabled Seafloor Seismic Observation System consists of seafloor repeaters and several equipments such as Seismometer, Tsunami sensor, Transmission Equipment, Power Feeding Equipment, Branching Unit, etc., placed on the seafloor. Data from these systems on the seafloor are transmitted on-line and in real-time by using optical fibers to land stations.(Fig8)

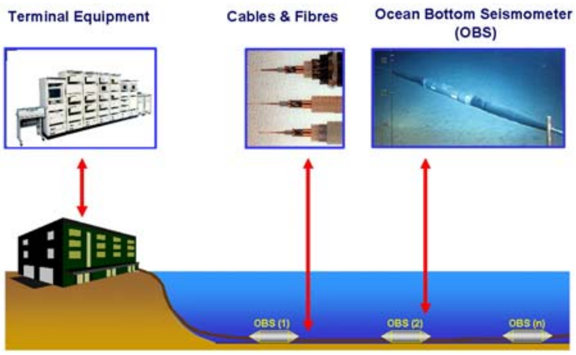

Fig8 Construction images

Observation Sensors: Seismometer and Tsunami Sensor

(Seismometer)

Seismometer is loaded with velocity meter and accelerometer.

In order to have accurate earthquake analysis data (North to South, East to West, Up to Down), it is necessary to adjust the position of the sensors because the surface of the seabed is not entirely flat. They are equipped with biaxial gimbals for positioning them when installed on the seafloor.(Fig9)

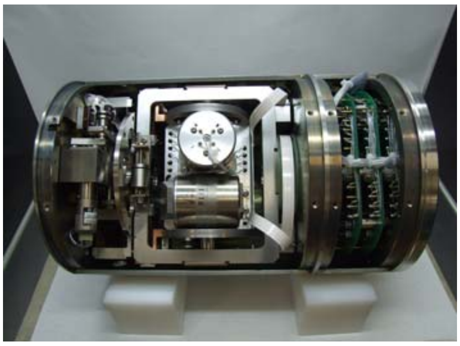

Fig.9 External view of seismometer

(Tsunami Sensor)

Since the Tsunami sensor is used for a long period of time on the deep ocean bottom, it must be highly resistive against seawater corrosion, not to speak of the necessity for waterproof and pressure-resistant design. In addition, it must directly detect seawater pressure with high accuracy and resolution by using a quartz pressure gauge, utilizing the piezoelectric phenomenon of a quartz oscillator, was used as a protective frame to protect it from mechanical damage during its installation. Accordingly, extremely high level techniques are required for mechanical design to detect the seawater pressure valuation.

4 DATA TRANSMISSION EQUIPMENT

Data Transmission Equipment uses an Analogue to Digital (AD) converter, Counter Circuit which converts observed physical data (Analogue) into telecommunication data (Digital). It multiplexes and classifies those data as well.

To deal with separate function (sensing and transmission), control and operation of the sensors is enabled from the land stations. Each of the sensors is loaded with its own application software.

In general, Earth Observation needs only 100Hz range to transmit data. Data is collected on a 10 second and 100 second basis. It took much effort to improve the quality of the telecommunication network with higher data transmission capacity and to establish transmission speeds of Mbps and Gbps. (Fig.10)

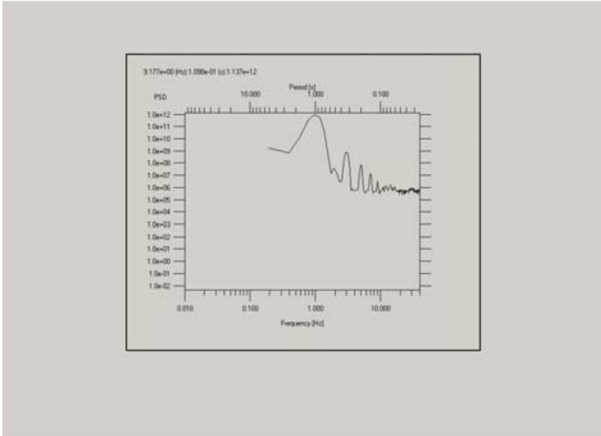

Fig.10 An example of seismometer's spectrum data

Power Feeding Equipment, Submarine Cable, and Power Feeding Electric Circuit

Power Feeding Equipment including other structural devices with high voltage endurance and pressure resistance, supplies constant current to ensure the system functions.

5 THE HISTORY AND THE DEVELOPMENT OF THE SEISMIC OBSERVATION SYSTEM (ROAD MAP)

The system development stages can be divided into three parts.

Off Omaezaki System in 1979

The first real-time earthquake observation cable system on the ocean bottom is named "Off Omaezaki System", which was built by the Japan Meteorological Agency (JMA) in 1979. Analogue Data Transmission method (Frequency Modulation method: the range is about 70dB in the SN ratio) was applied to this first system. The highly reliable Velocity Type Seismometer, which was made to be used on land was installed on biaxial gimbals and placed in a pressure resistant container. Since its deployment to the present, this system has constantly been observing and transmitting earthquake data from ocean bottom on a real-time basis.

Off Izu System in 1994

The "Off Izu System" was constructed by the Earthquake Research Institute of Tokyo University in 1993, and is the first system which applied the Optical Digital Transmission method and enabled seaquake observation with high accuracy and wide dynamic range. The success of the implementation of a 30km system using 1.3μm module contributed to the construction of the observation system using optical-fiber cable which could extend more than 100 km in the next stage in 1996.

The system made it possible to obtain a range of earthquake scale up to 1(one) gravitational acceleration (9.8m/s^2) and coastal noise up to several μKine on the transmission base, and succeeded in transmitting digitizing data using 16bit AD converter as over-sampling by basic Time Division Multiplexing (at 8K words, 192CH, 1.544Mbps) .

Off Kushiro System in 1999

The Off Kushiro System, the latest system which was deployed by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), started its observation in 1999. This system also utilizes optical data transmission technology.

At first, the Optical Observation System adopted Simultaneous Observations with the synchronized system clock of bidirectional transmission.

Later, the 1.55μm Laser Diode (LD) was adopted, which enabled performance of long distance observation. The total length of the system, including the Optical Amplifier, extended over 200 km long.

In addition, the system clock speed also became much faster. Then this system adopted the AD converter of the 24 bit Sigma-Delta type.

This system has several sensors which enabled not only Earthquake and Tsunami observation but also ocean environment observation: Salinity, Temperature of seabed, Current speed of seafloor and so on.

The system is characterized by using an add-drop multiplexer to direct the signals down one path or the other, which lead to network diversification from bidirectional system.

"TONANNKAI" off Omaezaki: Our new ongoing Seismic Observation System project.

It has been about 30 years since the first Seismic Observation System, "Off Omaezaki System", started in 1979. The Japan Metrological Agency is planning to install a new system, as the No.8 system in the same area. (Fig11)

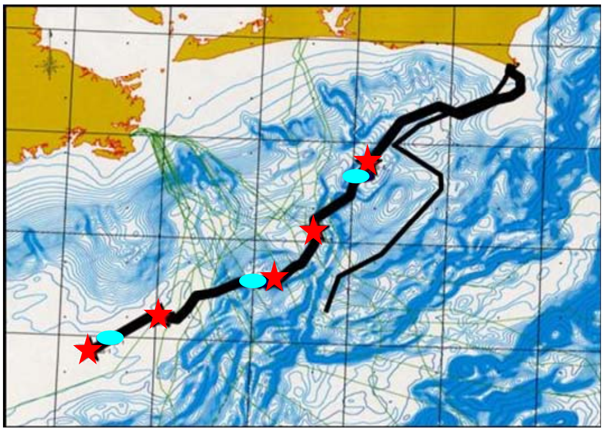

Fig11 New Seismic Observation System in OMAEZAKI system

This new system is planned to become the integration of Earthquake Observation Systems with high reliability and performance.

This new "OMAEZAKI system" project started in 2004. We are presently manufacturing the equipment for the system. All the necessary equipment provision will be finished by the end of this year, 2007. The installation of the system is scheduled to be completed in 2008. This ongoing system will be deployed at off OMAEZAKI area of TONANNKAI. This area has a high probability of having a large earthquake in the near future.

In addition to this project, we also have another larger-scale network system project under the development.

6 CONCLUSION

This paper has described how we have developed the Seismic Observation System over the last three decades with the objective of enhancing the quality and increasing the number of the systems.

The collision of oceanic and continental plates is the main reason of the occurrence of huge scale Trench Type Earthquakes. In Japan these are due to the Japan Trench being located on 4 main plates which slightly move at a rate of about 8 cm per year and collide against each other. The Seismic Observation Systems were deployed in order to detect these crustal movements and other phenomena as it might occur prior to Earthquakes and Tsunami to provide significant information to enable early warning of earthquake events in real-time.

The 7 Seismic Observation Cable Systems on the seabed around Japan have been fully functioning without any malfunction since deployment. We have been dedicated to the development and manufacture of all aspects of system and have contributed significantly to the improvement of system performance. The Cable Seafloor Seismic Observation System consists of seafloor repeaters, Observation sensors, including Seismometer and Tsunami Sensor, and several equipments such as Transmission Equipments, Power Feeding Equipments all placed on the seafloor. Data from these sensors on the seafloor are transmitted on-line by using optical fibers to land stations.

There are 7 Seismic Observation Systems and their main development can be divided into three stages. The first real-time observation cable system using Analog transmission method with only about 70dB in the SN ratio was established in 1979. Then the system established in 1994 was greatly improved to be capable of extending the cable up to 30 km using 1.3µm module, which contributed to the concept of the observation system using optical-fiber cable which extended more than 100 km in the next stage. The latest system established in 1999 successfully extended the total length of the system, including Optical Amplifier, to more than 200 km long using 1.5µm LD. In addition to this improvement, AD converter became capable of being increased to up to 24 bit data(over 120dB). Now we have the ongoing project as our No.8 Project.

We believe that providing accurate earthquake and tsunami information on a real time basis obtained from cable type Seismic Observation Systems is one of the most useful methods to decrease the damage which occur following earthquakes. We truly believe that this system, in combination with land based Earthquake Early Warning Systems, will perform a significant part to minimize the damage to human activities due to earthquakes.

7 REFERENCES

Mikio Suzuki, Isao Amikura, Shuzo Fujii & Junichi Goto (1980) Ocean-Bottom Seismograph Observation System. NEC Research & Development. P57-58.