Seismic Monitoring System using Optical Fiber and DAS (Distributed Acoustic Sensing) Technology

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DAS (Distributed Acoustic Sensing) technology has been introduced more than 5 years ago for the demands of pipeline monitoring and intrusion detection in Oil & Gas business. The latest optical fiber sensing technology using ‘Phase’ data now allows DAS to record Seismic signal including VSP (Vertical Seismic Profiling). The system is called ‘hDVS’ (heterodyne Distributed Vibration Sensing) in order to distinguish from pipeline monitoring system.
Unlike conventional seismic recording system, which usually use electro-magnetic sensor or Geophone, hDVS/DAS uses optical fiber as vibration sensor. It measures dynamic strain of the optical fiber, either SMF (Single-Mode Fiber) or MMF (Multi-Mode Fiber) for entire length or the section defined by the system. In case of SMF, the maximum length of the optical fiber is around 50km with current system, while the maximum length is reduced to around 10km for MMF, depending on the level of optical signal loss and optical sampling frequency. We are currently developing new system, which would be able to record over 50km length of SMF (100km is theoretical maximum length for hDVS/DAS).
There are several advantages of hDVS/DAS system compare with current seismic monitoring system such as:
a) Able to use existing optical fiber installations as seismic sensor instantly.
b) One system can measure line sensor as long as 50km rather than dot sensor.
c) Easier to expand as monitoring network by using existing optical fiber network.
d) Spatial resolution and gauge length can be set as parameters.
e) Core part of optical fiber is made of high-silica glass which can be installed at harsh environment over 200 degC where conventional sensors cannot be used.
f) Optical fiber is a passive component and no high risk of failure.
There would be more benefits can be identified.
During the presentation, mechanism of hDVS/DAS system will be explained followed by examples of seismic data recorded during Field trials last few years.

Keywords: DAS, hDVS, Optical Fiber, Laser, Seismic Monitoring

Seismic velocity change in Tokai region detected by Morimachi ACROSS

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In this study, we monitored seismic waves generated by Morimachi ACROSS using High sensitivity seismograph network Japan (Hi-net) stations in Tokai region, and detected two types of temporal travel time changes, secular change and co-seismic change at the time of the 2011 Tohoku-oki Earthquake. We associated the secular and co-seismic changes to closing and opening of the cracks beneath the region due to tectonic strain and strong shaking of the ground, respectively.
ACROSS (Accurately Controlled Routinely Operated Signal System) is a kind of artificial seismic source system for monitoring the temporal variation in propagation properties of seismic waves in the crust. We measured temporal variation in the travel time of S-wave during a period from 2007 to 2014 at five Hi-net stations within 35km away from the ACROSS source. The temporal variation of each component was fit by secular, annual, half-annual and offset at the time of the 2011 Tohoku-Oki earthquake (Fig.1).
In all stations, the secular changes were advance in contrast that the co-seismic changes were delay. The secular advances ranged from 0 to 1 ms/yr and the co-seismic delays ranged from 0 to 5 ms. Both the secular and co-seismic changes showed significant polarization anisotropy. The secular advances were larger in NW component in the five stations. On the other hand, the co-seismic delays were larger also in the same NW component (Fig.2).
If we assume travel time was changed by closing or opening of cracks, the anisotropic changes suggest the selective closing and opening of the cracks in the NE direction. We analyzed the crustal strain during the observation period using GNSS earth observation network system (GEONET). This region showed NW-SE compression and NE-SW extension as the inter-seismic and co-seismic strain, respectively. For the secular changes, inter-seismic strain is well-matched to suggested crack closing. Thus the secular changes may reflect the stress changes in the crust due to tectonic stress buildup. In the co-seismic changes, the co-seismic strain don't match to suggested crack opening. Thus we give the following interpretation. In this region, the crack density in the strike of NE is larger than that in other directions. The strong shaking of 2011 Tohoku-Oki earthquake caused spontaneous opening of all cracks due to increase of pore pressure. So the observed anisotropy should reflects persistently existing preferred orientation of cracks. Considering the geological structure of Tokai region, the interpretation may possible.

Acknowledgments.
We used the data by Hi-net, provided by National Research Institute for Earth Science and Disaster Prevention.

Reference

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Figure Caption
Fig1. Travel time advance at Kakegawa Hi-net station

Blue and red open circles show observed and predicted travel time advance with reference to Feb 28, 2007.
Predicted one is expressed by linear combination of secular, annual, half-annual variations and offset at the time of the 2011 Tohoku-Oki earthquake (red vertical line).
Fig2. Co-seismic (top) and Secular (bottom) travel time changes
Star shows the location of Morimachi ACROSS source. Ellipses show travel time variations with uncertainty expressed by their width of the arc colored by red (advance) and blue (delay). The axes of each ellipse correspond to the travel time variation of Tt and Rr components.

Keywords: seismic ACROSS, seismic velocity change, travel time change, Hi-net, Tokai region

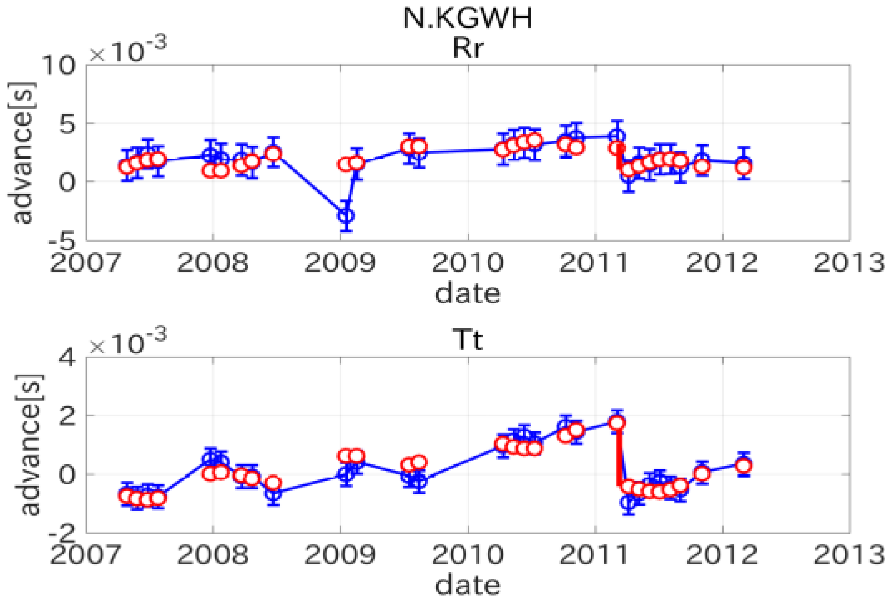

Fig.1 Travel time advances at Kakegawa Hi-net station

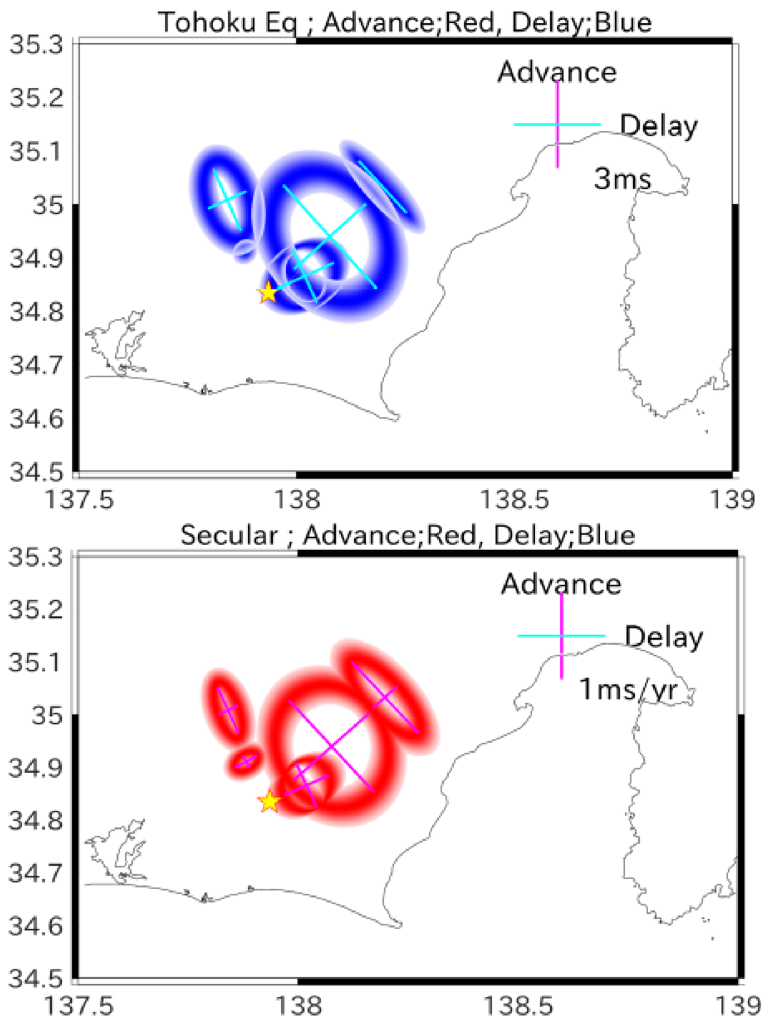

Fig.2 Co-seismic (top) and Secular (bottom) travel time changes

Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net) - Construction of subsea part of the S-net -

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NIED (National Research Institute for Earth Science and Disaster Prevention) has launched the project of constructing an observatory network for tsunami and earthquake on the seafloor, after the occurrence of the 2011 off the Pacific coast of Tohoku earthquake by the reflection that we could not monitor the expanse of the earthquake and the tsunami outbreak on site and in real time due to poor coverage of observation in ocean area. The project has been financially supported by MEXT (Ministry of Education, Culture, Sports, Science and Technology - Japan).

The observatory network was named “S-net”. S-net consists of 150 seafloor observatories which are connected in line with optical cables. The total length of submarine optical cable is about 5,700km. S-net system extends along Kuril and Japan trenches around Japan islands from north to south covering the area between southeast off island of Hokkaido and off the Boso Peninsula, Chiba Prefecture. Each observatory equips two sets of quartz type pressure gauge and four sets of three-component seismometers. Digitized data from those sensors are transmitted to land and used for early warning and precise measurement for earthquakes and tsunamis.

Two Japanese cable layer ships, which are specially designed for installation and repairing of submarine telecommunication cables, have been used for installation of the S-net submarine cable system. The S-net submarine cable system including the observatories is buried 1m beneath the seafloor to prevent from interference with fishing industry in the area shallower than 1,500m water depth. Those cable layer ships have capabilities of burying submarine cables. The S-net submarine cable system was originally designed to be deployed with the cable layer ships.

Three of authors are now board on C/S SUBARU, which is one of two cable layer ships described above, and in charge of installation of a subset of the S-net submarine observatory network which covers the area between east off Aomori Prefecture and south off island of Hokkaido. Installations of 23 observatories and about 800km length optical cable on the seafloor will be completed shortly after.

We will report the progress of the construction of S-net submarine cable system in this presentation.

Keywords: Seafloor Observatory Network, Tsunami, Submarine Earthquake

Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net) - System of landing station part -

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Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net) project to construct a large-scale seafloor network of cable-linked observatories is in progress around Japan Trench and Kuril Trench in Japan. The S-net consists of 150 ocean bottom earthquake and tsunami observation stations, ocean bottom fiber optic cables which are about 5,700 km in total length, landing stations, IP-VPN network which delivers data to data centers, and data centers. The ocean bottom fiber optic cables connect the observation stations to land, and they are drawn inside landing stations.

We have constructed five landing stations; Minamiboso station in Minamiboso City, Chiba Pref., Kashima station in Kashima City, Ibaraki Pref., Watari station in Watari Town, Miyagi Pref., Miyako station in Miyako City, Iwate Pref., and Hachinohe station in Hachinohe City, Aomori Pref.. The Watari station is located on the third floor of reinforced concrete building, and other stations are container-type data centers.
In the landing station, there are a high voltage receiving transformer equipment, an emergency diesel generator with a tank which can store fuel for one week, uninterruptible power supplies (UPSs), a power feed equipment (PFE) that supplies constant DC current (1.1 A) to a submarine cable and observation units, optical receiver transmission equipment, optical wavelength division multiplexing equipment (WDM), GPS clocks, data conversion servers, data transmission servers, supervisory equipment, and so on.

In each earthquake and tsunami observatory under sea water, there installed two sets of three component servo accelerometers, a set of three component velocity seismometers (analog outputs), and two quartz type depth sensors and a set of three-component quartz type accelerometers (frequency outputs). These data are transmitted to the landing stations as the digital data which synchronized to a GPS clock signal supplied from the landing station. The data of frequency outputs are frequency count values at sampling frequency of 8 kHz, and these of analog outputs are digitized values by 24 bits AD converter at sampling frequency of 1 kHz. Data conversion servers at the landing station receive these data. The 8 kHz frequency count data are converted into physical value data of 100 Hz (acceleration) or 10 Hz (water pressure and temperature), and these physical data are delivered to data transmission servers. The 1 kHz digitized analog data are converted into 100 Hz data by decimation filter, and delivered to data transmission servers.

The data received by data transmission servers will be transmit to Tsukuba data center, Tokyo backup data center, Japan Metrological Agency (JMA), and related institutions via two control center using an IP-VPN network.

Keywords: Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net)

Installation of compact seafloor cabled seismic and tsunami observation system using ICT

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A seismic and tsunami observation system using seafloor optical fiber had been installed off Sanriku, northeastern Japan in 1996 to obtain exact seismic activity and to observe tsunami on seafloor. This system is based on the tele-communication technology, and observation was performed continuously in real-time. In March 2011, the Tohoku-oki earthquake occurred at the plate boundary, and the system recorded seismic waves and tsunamis by the mainshock. These data are useful to obtain accurate position of the source faults and source region of tsunami. However, the landing station of the system was damaged by huge tsunami, and the observation was suspended. Because the real-time seafloor observation by cabled system is important in this region, we decide to reconstruct a landing station and install newly developed Ocean Bottom Cabled Seismic and Tsunami (OBCST) observation system for additional observation and/or replacement of the existing system.
From 2005, we have been developed the new compact Ocean Bottom Cabled Seismometer (OBCS) system using Information and Communication Technology (ICT). Our system is characterized by securement of reliability by using TCP/IP technology and down-sizing of an observation node using up-to-date electronics technology. In 2010, the first OBCS was installed in the Japan Sea. The new OBCST system is placed as the second generation of our system, and uses standard TCP/IP protocol with a speed of 1 Gbps for data transmission, system control and system monitoring. The Wavelength Division Multiplexing (WDM) is also introduced to reduce number of optical fibers. There are two types of observation nodes. Both types have accelerometers as seismic sensors. One type of observation nodes equips a crystal oscillator type pressure gauge as tsunami sensor. Another type has an external port for additional observation sensor by using Power over Ethernet technology. Clock is delivered to all observation nodes from the GPS receiver on a landing station using simple dedicated lines. In addition, clock can be synchronized through TCP/IP protocol with an accuracy of 300 ns (IEEE 1588). A simple canister for tele-communication seafloor cable is adopted for the observation node, and has diameter of 26 cm and length of about 1.3 m.
A route for the new OBCST was selected in consideration of those of the existing cable and plans for another new cable system, and results form a route survey in 2013. According to the route plan, the system has a total cable length of 105 km and 3 observation nodes with 30 or 40 km spacing. Two observation nodes have a built-in tsunami meter, and the furthest observation node has the PoE port. At the deployment of the cable system, we attached a precise pressure gauge with digital output to the PoE port.
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. An end of cable 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 observation node closest to the coast were simultaneously buried with using a plough-type burial machine. Burial depth is 1 meter below the seafloor. Finally, a remote operated vehicle buried the submarine cable around the landing point. After finishing of the deployment, data recording was immediately started.
From the seismic data from the new system, it is found that the noise levels are comparable to those at the existing cabled system off Sanriku. In addition, it is confirmed that burial of the sensor package is effective noise reduction. For water pressure data, pressure gauges have a

resolution of less than 1 hPa. Data from all the sensors both the new system and the existing system are consistent.

Keywords: Cabled seafloor observation system, Ocean bottom seismometer and tsunami meter, Real-time observation