Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net) - Current status of the S-net construction -

*Masashi Mochizuki[1], Kenji Uehira[1], Toshihiko Kanazawa[1], Takashi Shimbo[1], Katsuhiko Shiomi[1], Takashi Kunugi[1], Shin Aoi[1], Takumi Matsumoto[1], Shoji Sekiguchi[1], Narumi Takahashi[1], Takeshi Nakamura[1], Naotaka Yamamoto[1], Masanao Shinohara[2], Tomoaki Yamada[2]

1. National Research Institute for Earth Science and Disaster Resilience, 2. Earthquake Research Institute, University of Tokyo

The only real time seafloor monitoring system situated inside the 2011 off the Pacific coast of Tohoku earthquake (the 2011 Tohoku earthquake) source area at the time of the earthquake was the ocean-bottom seismic and tsunami observation system off the Sanriku coast deployed and maintained by Earthquake Research Institute, University of Tokyo. Three seismic and two tsunami observatories were installed on the system. We did not have adequate observatory networks which could measure and monitor earthquakes and tsunamis on the seafloor, even though a lot of earthquakes occur beneath the seafloor around Japan.

NIED (National Research Institute for Earth Science and Disaster Prevention) has launched the project of construction of an observatory network for tsunami and earthquake on the seafloor just after the occurrence of the 2011 Tohoku earthquake. It reflected on the situation that we could not monitor the outspread 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 seismic and tsunami observatory network was named “S-net”. The S-net consists of 150 seafloor observatories and covers the focal region of the 2011 Tohoku Earthquake and its vicinity regions. Each observatory equips two sets of pressure gauge and 4 sets of three component seismic sensors. The 150 seafloor observatories are connected in line with submarine optical cables. And those optical cables are landed at 5 sites (Hachinohe-city, Miyako-city, Watari-town, Kashima-city and Minami-Boso-city) on the Pacific coast of Tohoku district, so then the S-net provides a real-time monitoring of earthquake and tsunami on the seafloor.

Six years has passed since the project started in 2011, the S-net seafloor observatory network is going to reach completion. Some data are being transmitted to Japan Meteorological Agency, and have been already used for surveillance of earthquakes and tsunamis. Full-scale operation of the S-net is expected to start in April, 2017.

We will report the current status of the construction of S-net seafloor observatory network in this presentation.

Keywords: S-net, seafloor observatory network, earthquake, tsunami

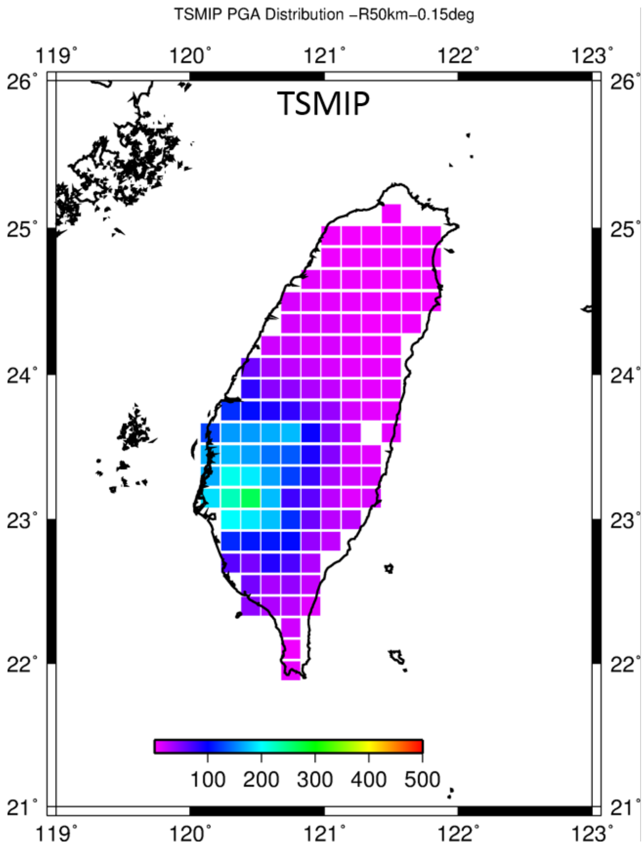
Toward a near real-time shaking map using the P-alert seismic network in Taiwan

*TA-YI CHEN[1], Yih-Min Wu[2]

1. Seismological Center, Central Weather Bureau, Taiwan, 2. Department of Geosciences, National Taiwan University, Taiwan

Shaking maps are one of the useful information for hazard assessment after earthquakes occurred. Based on dense and real-time seismic network the detailed and fast shaking maps are available. The Central Weather Bureau of Taiwan (CWB) has operated two strong motion seismic networks. One is the real-time strong motion seismic network, named RTD, consisting of 110 stations. It can provide a shaking map within 15 minutes after an earthquake occurred. The other is the dense seismic network named Taiwan Strong Motion Instrument Project (TSMIP) consisting of more than 800 stations. However, the shaking map generated by the RTD seismic network cannot reveal actual ground motions due to poor station density. The TSMIP seismic network cannot transmit data in real time. Recently, the low-cost Micro-Electro Mechanical System (MEMS) accelerometers has been deployed in Taiwan, named P-alert seismic network, with about 609 stations transmitting data to the center in real time. The P-alert seismic network provides an opportunity to provide quick and real shaking map, but the ground motion records from the P-alert need to be corrected because all P-alert sensors deployed on the wall or pillar of buildings. To obtain real ground motion without building influence, we proposed an approach using TSMIP records to construct a transfer function for the P-alert records. Finally, once an earthquake occurred using the real-time P-alert data streams and corrected by the transfer function, the real ground-motion shaking maps become available.

Keywords: seismic network, shaking map, low-cost seismometer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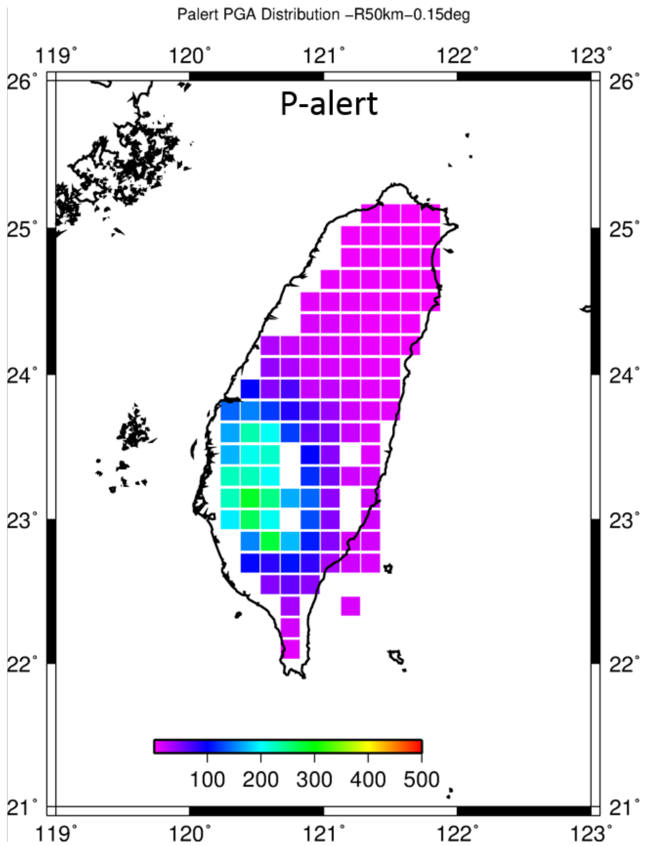
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Frequency response evaluation of broadband seismometer in primary calibration using laser interferometer

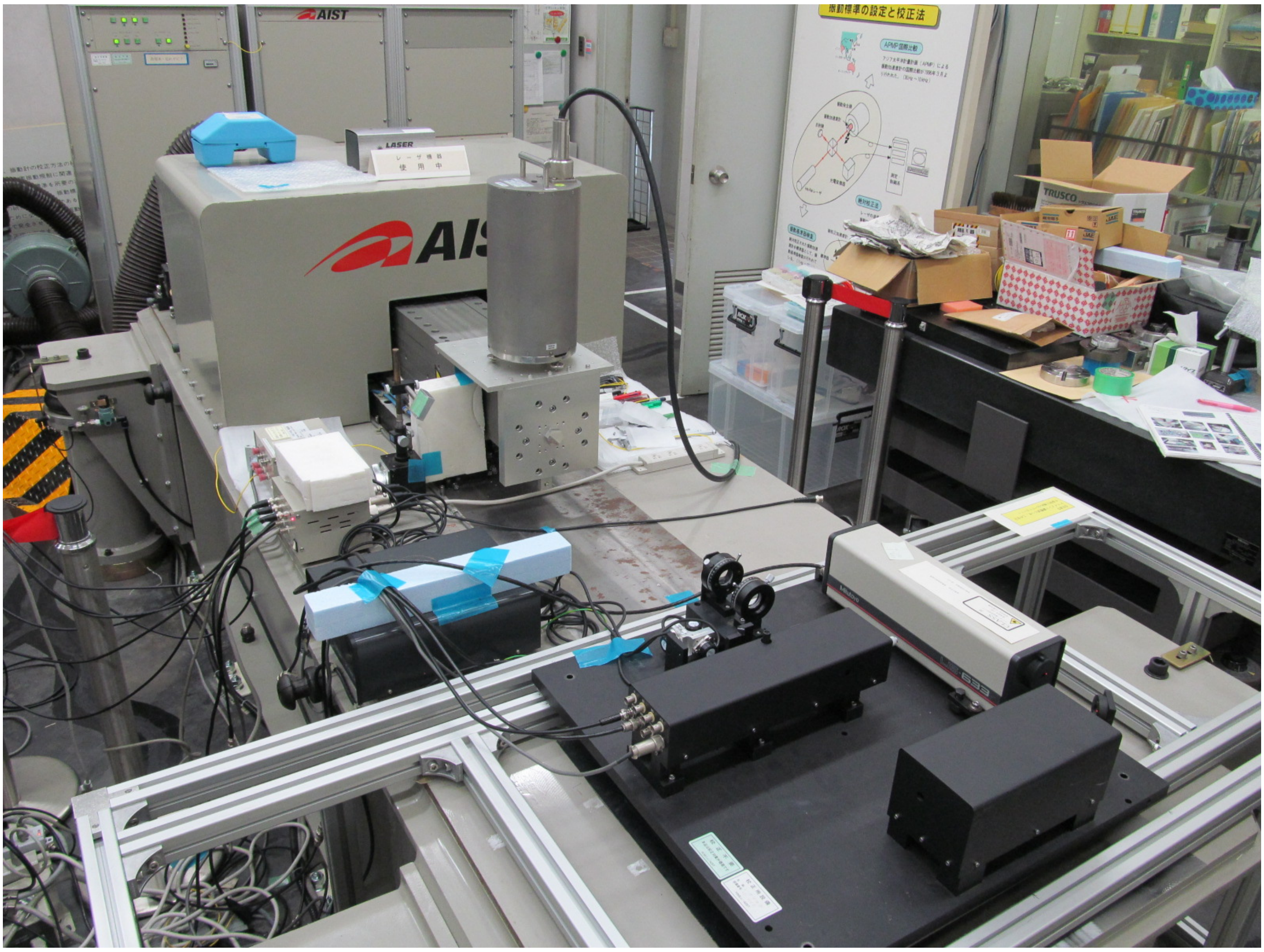
*Hideaki Nozato[1], Wataru Kokuyama[1], Akito Araya[2]

1. National Institute of Advanced Industrial Science and Technology, 2. The University of Tokyo

Broadband seismometers have wide measurable frequency range, and are used for analysis of hypocenter mechanism by monitoring nearby and far seismic waves. Since the broadband seismometer has a bandpass characteristic with a low cut-off frequency of 0.01 Hz or less in the low-frequency range, in order to evaluate its frequency response, it is necessary to use a vibration exciter which precisely oscillates at low frequency and the measurement system. Therefore, a broadband seismometer was evaluated using low-frequency calibration facility developed by AIST.
This low-frequency calibration facility consists of a vibration exciter and a laser interferometric measuring system, and vibrates an accelerometer to be evaluated with a vibration exciter and measures its vibration displacement with the laser interferometric measuring system. The vibration exciter is a specific-manufactured dynamoelectric type with air bearing which has a stroke length of 0.4 m and the maximum loading capacity that can be excited with less than 30 kg. On the other hand, the laser interferometric measuring system equips a two-phase detection type homodyne laser interferometer with a stabilized He-Ne laser source (wavelengh 632.8 nm), and detects quadrature signal with the difference of orthogonal phase each other in relation to the vibration displacement. The quadrature signal is recorded at a sampling frequency of 10 MHz, the vibration displacement is calculated from phase angles normalized by 2p per half wavelength obtained by arctangent and phase unwrapping in the signal processing program. Simultaneously, from the broadband seismometer, the voltage signal of the velocity is also recorded at a sampling frequency of 200 kHz with 24 bits high resolution. By applying sine approximation to both the displacement and voltage signals, then the sensitivity of the seismometer is obtained from the ratio of the velocity and the voltage amplitudes. Furthermore, from the initial phases of both sine approximated, the phase lag of the seismometer is also calculated. In this way, obtaining the output quantity of electricity per input acceleration of the accelerometer using the laser interferometer with the length standard, is called primary calibration and is internationally documented as ISO 16063-11.
AIST, a national metrology institute (NMI), is responsible for ensuring the reliability of the measurement of the low-frequency calibration facility, international equivalence and its traceability in order to supply the acceleration standard to the industry. Therefore, also in the calibration of the seismometer, the velocity is the assembly quantity of the length and the time, and the output signal is the electric quantity, so these quantities shall be traceable to the national standard. The stability of the He-Ne laser wavelength is guaranteed on the basis of CIPM recommendation and the time standard is secured by the JCSS calibrated rubidium time base. The electric standard also secures its traceability using a JCSS calibrated DC voltage generator. Regarding measurement reliability and international equivalence, in the international comparison of low-frequency vibration (CCAUV.V-K3) where NMIs compare the calibration and measurement capability mutually, the world’s best uncertainty of 0.15% and international equivalence.
Information on the frequency response of broadband seismometers is given by cut-off frequencies or the table of pole and zero described in the test report by the manufacturer. Since observation data of seismic waveform is corrected and analyzed using that information, the reliability of frequency response is significant, but there are few cases reported on its accuracy and stability. In this study, since we calibrated the frequency response of Guralp CMG-3T using a low-frequency calibration facility and verified the

consistency with the test report by the manufacturer, the results will be presented.

Keywords: primary calibration, laser interferometer, broadband seismometer, frequency response



Progress of Seismic Monitoring System using Optical Fiber and DAS Technology

*Tsunehisa KIMURA[1]

1. Schlumberger

During the JpGU 2016, I introduced that DAS (Distributed Acoustic Sensing) technology has been used since 2011 for the demands of pipeline monitoring and intrusion detection in Oil & Gas business, and the latest optical fiber sensing technology using 'differential phase' data now allows DAS to record seismic signal including VSP (Vertical Seismic Profiling). The system is called 'hDVS' (heterodyne Distributed Vibration Sensing). Now, new tier-3 hDVS system has introduced in H2 2016.

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 a section defined by the user. In case of SMF, the maximum length of the optical fiber is around 40km with tier-2 hDVS system, while the maximum length is reduced to around 10km for MMF, depending on the level of optical signal loss and optical sampling frequency. With using new tier-3 hDVS system, it would be able to record longer (50km or longer) the length of SMF (100km is theoretical maximum length for hDVS/DAS). In addition, the S/N ratio of the data was improved by 15dB in Lab environment.

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.
b)One system can measure line sensor over 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.
g)In the case sensing fiber is broken by earthquake/tsunami, seismic monitoring can still be continued from the damaged point.
h)Using WDM (Wavelength Division Multiplexing), there is a potential to use one fiber for both communication and seismic monitoring.

There would be more benefits can be identified.

Keywords: DAS, hDVS, optical fiber, seismic monitoring, earthquake, tsunami

Development of JAMSTEC Ocean-bottom Seismology Database (J-SEIS) to download DONET Event Data and Borehole Continuous Data (3)

*Hiroki Horikawa[1], Kensuke Suzuki[1], Kentaro Sueki[1], Eiichiro Araki[1], Akira Sonoda[1], Narumi Takahashi[1,2], Seiji Tsuboi[1]

1. Japan Agency for Marine-Earth Science and Technology, 2. National Research Institute for Earth Science and Disaster Prevention

Japan Agency for Marine-Earth Science and Technology (JAMSTEC) have developed a database of seismic data observed in the Nakao Trough in southwest Japan. We have operated JAMSTEC Ocean-bottom Seismology Database (J-SEIS)* for research and education since April 2016.
J-SEIS is download system of seismic waveform data, the downloadable data are continuous data of Long-Term Borehole Monitoring System (LTBMS) and event data of DONET (Dense Ocean-floor Network System for Earthquake and Tsunamis).
During IODP Exp. 332 in December 2010, the first LTBMS was installed into the borehole site (C0002:KMDB1) located 80 km off the Kii Peninsula, 1938 m water depth in the Nankai Trough. Furthermore, During IODP Exp. 365 in 2016, the second LTBMS was installed into the borehole site (C0010:KMDB2) located sea area off the Kii Peninsula. It consists of various sensors in the borehole such as a broadband seismometer, a tiltmeter, a strainmeter, geophones and accelerometer, thermometer array as well as pressure ports for pore-fluid pressure monitoring. The signal from sensors is transmitted to DONET in real time. J-SEIS allows users to download seismic waveform data as continuous data of SEED format.
Event data consists of strong motion (EH type) and broadband (BH type) seismograph data observed at DONET1, it is produced referring to event catalogues from USGS and JMA (Japan Meteorological Agency), Magnitude greater than 6 for far-filed and greater than 4 for local seismicity, respectively. This system allows users to download these seismic waveform data as event data of SEED format.
J-SEIS allows users to download continuous and event data on the graphical user Interface. Further, it is also possible to download directly seismic continuous data by specifying parameters (terms, channel, and station) of URL address (e.g. data download page like “Web Service” of IRIS).

* J-SEIS : JAMSTEC Ocean-bottom Seismology Database
URL https://join-web.jamstec.go.jp/join-portal/

Keywords: Chikyu, Borehole, DONET

Improvement of real-time seismic waveform display system for "Nankai Trough Region Earthquake Disaster Prevention Research Project"

*Sugiyama Daisuke[1], Morifumi Takaesu[2], Hiroki Horikawa[1], Kentaro Sueki[1], Yoshinobu Mizui[3], Narumi Takahashi[3], Akira Sonoda[1], Seiji Tsuboi[1]

1. Japan Agency for Marine-Earth Science and Technology, 2. Nippon Marine Enterprises, 3. National Research Institute for Earth Science and Disaster Resilience

Japan Agency for Marine-Earth Science and Technology (JAMSTEC) have operated DONET, which have been entrusted by NIED (National Research Institute for Earth Science and Disaster Resilience). DONET is a large-scale and dense seafloor seismic network including strong-motion seismometers and quartz pressure gauges, around the Kumano Nada which assumed focal region of the Nankai Trough earthquake. DONET realizes the observation of physical phenomena such as earthquakes, crustal deformations, and tsunamis in real-time. In order to actively disseminate research information using DONET, we have developed web application system, REIS (Real-time Earthquake Information System) that displays seismic waveform and pressure waveform on web browser in real-time, as a service for disaster managers.
With the influence of extreme hazards as the Kumamoto Earthquake and the Middle Tottori Earthquake in 2016, Local Public Entities, in coastal areas due to large tsunamis, have been following the wide-area anti-disaster measures indicated by the Japanese Government. In addition, they are required to construct anti-disaster measures according to the area as soon as possible. By the use of REIS, disaster managers may make decisions for disaster prevention before the tsunami arrival, based on the observed waveform displayed from the observation data immediately above or near the earthquake occurrence zone in real-time.
Since 2013, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has started the "Nankai Trough Region Earthquake Disaster Prevention Research Project" which conducts research on anti-disaster measures of the Nankai Trough Earthquake. Their workshop has been divided into four areas of the Tokai region workshop, the Kansai region workshop, the Shikoku region workshop, and the Kyushu region workshop, and they have been discussing anti-disaster issues specialized in each region. In 2016, we have started to provide our waveform display function for this workshop's page, and have promoted regional disaster prevention using REIS to more disaster managers.
We have been requested from NIED to expand the scope of user to more actual workers in the next fiscal year. Now, we are adding a feature to generate an image cache for waveforms to reduce load and a feature to hold and view past waveforms about weeks. It makes REIS possible to drastically expand the number of users. Also, it is possible to check the waveform of an earthquake and tsunami, even if user access REIS after a large earthquake.
In this presentation, we hope to discuss our system feature enhancement on future.

Keywords: Real-time Seismic Waveform Display, DONET, Nankai Trough Region Earthquake Disaster Prevention Research Project, Regional Disaster Prevention, Web Application

Orientations of DONET2 seismometers estimated from seismic waveforms

*Masaru Nakano[1]

1. Japan Agency for Marine-Earth Science and Technology

DONET (Dense Oceanfloor Network System for Earthquakes and Tsunamis) has been developed along the Nankai trough in order to issue earthquake and tsunami early warnings, monitor the crustal activities, determine the crustal structures, and reveal and monitor preparation processes of large megathrust earthquakes. DONET1 and DONET2 cover the Kumano fore-arc basin and the Muroto basin between off Shiono-misaki and off Muroto, respectively. All DONET2 stations have been installed by March 2016. Two new stations have been added to DONET1 to fill the gap between DONET 1 and 2 networks, off Shiono-misaki. Seismometer orientation is crucial for analyzing seismic waveforms. Nakano et al. (2012) obtained seismometer orientation of each DONET1 station. In this study, we estimated seismometer orientation of DONET2 stations and the new stations of DONET1. We also estimated the seismometer orientation at KMA03 in DONET1 because the seismometer package has replaced in December 2015.
We estimated the orientations of DONET seismometers by using the cross-correlation of long-period seismic waveforms with those at reference stations located in land (Shiomi et al., 2003). By using five F-net stations (KIS, KMT, NOK, ISI, and UMJ) installed at coastal area in the Kii Peninsula and the Shikoku Island as references, we estimated the direction of broad-band seismometer at each DONET station. We used data from 31 earthquakes that occurred between March 2015 and January 2017 in the world with magnitude larger than 7. The orientation of seismometer at F-net stations KIS and ISI are corrected by the angle of NS component shown in the web site.
We applied a Butterworth filter between 0.008 and 0.01 Hz for the waveforms. We rotated the horizontal components of waveforms at a DONET station and computed cross-correlation coefficient with NS and EW components at each F-net station. The angle that gives the maximum cross-correlation coefficient is the estimate of the seismometer orientation. We adopted the data with the sum of the correlation coefficients of the two components larger than 1.7. For robust estimations, we removed data with a deviation larger than 10 degree from the average, and computed the average again. The standard error for the orientations were between 1 and 2 degree.
We also estimated the seismometer orientations at DONET1 stations for comparison with those obtained by Nakano et al. (2012). The seismometer orientations differ by 4 degree at maximum at several stations. Number of data used for the estimations of such stations were relatively small compared to other stations in Nakano et al. (2016). This would be because that the analysis period was immediately after the construction of the network in the previous study.
We concern the same situation for estimations at DONET2 stations obtained in this study. Some stations were not buried after the installation and seismic noise in long-period components is larger, resulting in less number of data available. Increasing the number of data by using much number of events, as well as improving the data quality by burial of seismometer is important for increasing the accuracy of the estimations. Combination of estimations by using another method such as the orientation of P-wave first motion that was used in Nakano et al. (2012) also improves the accuracy.
Acknowledgements: Data obtained from F-net and DONET were used for the analysis.

Keywords: Ocean-bottom seismometer, Nankai trough

Survey of ground noise during stormy weather in Okinawa region

Toshio Kusano[1], Yutaka Nakama[1], Masahiko Noda[1], Hiroshi Yamashiro[1], Yoshiharu Kawajo[1], Tadashi Inaba[1], Yasuhiro shimoji[1], *Akio Katsumata[2]

1. Okinawa Regional Headquarter, JMA, 2. Meteorological Research Institute, JMA

It is well known that the number of detected earthquakes is less during stormy weather such as typhoons compared with that in fine weather in Okinawa region. Horimoto et al. (2016) showed the detectivity got lower due to high ground noise during a storm or a typhoon was passing near the Okinawa Islands. Whereas the felt earthquakes were detected even during the stormy weather, the detectable magnitude level increased by about one as earthquake magnitude. To reduce the effect of the bad weather, application of filter is considered to be effective to keep the detection level.

In this study, wind speed, oceanic wave height, and period of oceanic wave were referred to as indicators of the bad weather. As to the wind speed, the period of the wind speed (ten-minute interval value) larger than 15m/s was considered to be the stormy weather. Significant wave height more than 3 m and Significant wave period more than 10 s are also used as the threshold of the stormy weather. We used data of Itokazu station for the wind speed, and wave height and period at Hana NOWPHAS of Ports and Harbor Bureau. We retrieved 20 minute interval seismic wave data at the Tamagusuku seismic station.

We show two examples of the seismic data under the condition described above.
1) Nov. 27, 2015. Wave height greater than 3m.
A continental anticyclone was covering this region, and wave height of 4.18 m was recorded at Naha. The spectrum of 20 minute interval at Tamagusuku station showed peaks at 1 Hz and 3 Hz.
2) Dec. 17, 2015. Wave period longer than 10 s.
A continental anticyclone was covering this region, and significant wave period of 10.0 s was recorded at Naha. The spectrum of 20 minute interval at Tamagusuku station showed a peak at 1 Hz.

We will increase examples of seismic data during stormy weather, including data in Miyakojima and Ishigaki Islands.

Keywords: seismic noise, stormy weather, detectivity of earthquakes

Detection of the blast frequent areas based on the NIED Hi-net hypocenter catalog

*Katsuhiko Shiomi[1]

1. National Research Institute for Earth Science and Disaster Resilience

One of the important matters for constructing a daily hypocenter catalog is excluding information about artificial earthquakes and blasts. Automatic hypocenter determination system operated by NIED has the master database of blast frequent areas. By using this database, the system automatically determines that a detected event is whether a natural earthquake or artificial one. On the other hand, blast points sometimes move by changes of social activities (Okada, 1996). In this study, we extracted new blast frequent areas based on the NIED Hi-net hypocenter catalog for eight years (from April 2008 to March 2016). Then, we apply the same method to two years before and after the 2011 Tohoku earthquake, and check the time and spatial variation of the blast frequent areas in the Tohoku district.
Seismograms by blasts at quarries and construction areas are generally observed in the daytime (Okada, 1996; Taira and Tsumura, 2001). First, we extracted the manually confirmed blast events from the eight-year Hi-net catalog and confirmed that 99.5 % of the blast events were observed for 12 hours from 7:00 to 19:00. Thus, we set this time range as blast frequent time zone. As a basic unit for the blast frequent region evaluation, we defined small cells with the width of 0.025-degree. Based on the Hi-net hypocenter catalog for recent three years (April 2013 ~ March 2016), we extracted shallow (< 10km) events and counted the number within each cell. Cells where more than 90% events occurred during the blast frequent time zone were selected and named as **EVT**. We also labeled the cells as **MAN** where several blast events detected manually. The cells already selected in the Hi-net master DB were labeled as **MAS**. Comparing these cells, we confirmed that all **MAN** cells were included in **EVT** cells. Although more than 700 cells were only selected as **MAS**, 240 cells were newly extracted as **EVT**. Checking the event activity of each cell for the eight years' catalog, we confirmed that the former cells were two cases: the area where the detection of blast events was stopped and both the blasts and natural earthquakes were observed. In order to check the transition of the blast area before and after the 2011 Tohoku Earthquake, we prepared the Hi-net hypocenter catalog for three periods: Before the earthquake (Mar. 2009 to Feb. 2011), just after the earthquake (Apr. 2011 to Mar. 2013), and recent two years (Apr. 2014 to Mar. 2016). Using each catalog, cells where more than 90% events occurred concentrated within the blast frequent time zone were extracted. Although there were many active blast area along the Kitakami River in Iwate and Miyagi, Hama-dori district in Fukushima and Hitachi city in Ibaraki before the earthquake, few blast events were detected just after the earthquake. The activity of blasts was obviously reduced at not only the Pacific coast but also the inland area. In recent years, the activity has resumed at these areas and seemed to expand to the surroundings. This result shows that the progress of reconstructions from the earthquake damage.

Keywords: NIED Hi-net, Blast, Tohoku-Oki Earthquake, Hypocenter Catalog

2-D seismic reflection survey across the Izu Bonin forearc seamounts using the R/V *Kaimei*

*Tetsuo No[1], Yasuyuki Nakamura[1], Seiichi Miura[1], Gou Fujie[1], Shuichi Kodaira[1]

1. Japan Agency for Marine-Earth Science and Technology

The research vessel *Kaimei* (R/V *Kaimei*), completed in 2016, is the newest research vessel of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). This multipurpose research vessel conducts oceanic observations and research in multiple areas, such as earthquakes, tsunamis, submarine resources, and atmospheric and marine environments. One of the remarkable features of this vessel is that the seismic survey system complies with the specifications of four types: 3-D seismic surveys, high-resolution 3-D seismic surveys, 2-D seismic surveys, and seismic survey using ocean bottom seismographs (OBS). As part of a sea trial of seismic system, JAMSTEC and Mitsubishi Heavy Industries conducted a 2-D seismic reflection survey in the Izu Bonin forearc in January 2017. A trial seismic line was set across the Torishima and Torisu seamounts, which are dotted along the landward slope of the trench westward of the Izu Bonin Trench. Furthermore, drilling research by the Ocean Drilling Program (Fryer et al., 1990), crustal structure study using OBSs (Kamimura et al., 2002), and observation by the deep submergence research vehicle *SHINKAI 6500* (Fujioka et al., 1995) were conducted near the survey line. These studies revealed that the seamounts were formed as serpentinite seamounts. Therefore, this seismic data may be important to study the internal structure of these serpentinite seamounts.
Following are the data acquisition specifications of this survey: The shot spacing was 50 m and the record length was 13 s. The tuned air gun array had a maximum capacity of 10,600 cu in (approximately 173.7 L) and comprised 44 air guns. The standard air pressure was approximately 2,000 psi (approximately 14 MPa). The air gun array was kept 10 m below the sea surface throughout the experiment. During the air gun shooting, we towed a 1920-channel hydrophone streamer cable. The receiver interval was 3.125 m, and the cable was approximately 6 km long. The towing depth of the streamer cable was maintained at 12 m below the sea surface using depth controllers. Since the receiver interval and common midpoint interval of the *Kaimei* system are 1/2 to 1/4 times as narrow as those of general multichannel seismic reflection systems, seismic data of the *Kaimei* system should operate effectively for processing waveform data of spatial direction, such as the suppression of spatial aliasing, migration, and velocity filter, if we acquire good quality data.
We introduce an outline of multimode seismic systems of the R/V *Kaimei*, and report about a seismic reflection data across the Izu Bonin forearc seamounts.
Acknowledgments: We thank Mitsubishi Heavy Industries Ltd. and Marine Technology Center of JAMSTEC for their effort in acquiring a seismic data in a sea trial of the R/V *Kaimei*.

Keywords: seismic reflection survey, spatial aliasing, Izu Bonin forearc

Characterization of earthquakes in terms of high frequency seismic signal durations, velocity and acceleration amplitudes

*Tatsuhiko Hara[1]

1. International Institute of Seismology and Earthquake Engineering, Building Research Institute

Hara (2007a, EPS) developed a magnitude formula, referred to as M_{hdd} (Hara, 2013, SSJ), in which high frequency seismic signal durations and maximum displacement amplitudes measured from tele-seismic P waves are used. Hara (2007b, EPS) showed that tsunami earthquakes were characterized by longer high frequency seismic signal durations and smaller displacement amplitudes. Since there exist events which are not tsunami earthquakes that have similar characteristics, it is difficult to distinguish tsunami earthquakes only by the above observables.

We investigated a possibility to characterize tsunami earthquakes by high frequency seismic signal durations and maximum velocity and acceleration amplitudes. The dataset consists of waveform data recorded at the GSN stations in the epicentral distance range between 30 and 85 degrees for large (the minimum M_w is set to 7.2) shallow events that occurred between 1994 and May 2015, which were used to revise the M_{hdd} formula.

We show that tsunami earthquakes are characterized by longer high frequency seismic signal durations and smaller velocity and acceleration amplitudes more clearly than in case displacement amplitudes are used. This suggests a possibility to distinguish tsunami earthquakes through simple measurements of high frequency seismic signal durations and velocity and/or acceleration amplitudes.

Keywords: tsunami earthquake, high frequency seismic signal duration

Application of the simple technique to estimate subsurface structure with sloped engineering bedrock to microtremor array observation records

*Kahori Iiyama[1], Hitoshi Morikawa[1], Kohei Tanaka[2], Kimitoshi Sakai[2]

1. School of Environment and Society,Tokyo Institute of Technology, 2. Railway Technical Research Institute

Regarding a long-continuous civil engineering structure such as a railway structure, the geological profile under the structure is not identical and the significant difference in geological property within the limited area possibly induce unexpected seismic behavior in the structure. To ensure the reliability in seismic safety evaluation, the ground property at an objective site should be estimated with appropriate resolution.

As one of the simple and easy techniques to estimate the representative velocity structure, the H/V spectral ratio (RH/V) is widely used, which requires only one observation point. The predominant period (TH/V) of RH/V likely indicates the resonant period of the objective ground. The representative thickness of the subsurface layer can also be identified if the shear wave velocity is known.
The technique, however, theoretically supposes that the layers are flat and spread infinite as same as most of the methods. In other words, the applicability to irregular ground, e.g. the engineering base surface is steeply sloped, is uncertain.

In recent study, Zhang et al. (2015) proposed the estimation technique using only vertical records of two observation sites. It has not only the same advantage as the H/V technique with respect to the simplicity but has the potential to extract the amplification characteristics generated by the sloped bedrock surface. The technique is based on the theory that the cross-spectral density function between two sites for each component can theoretically be shown as the function of three factors: the energy density of the waves Es, the wave number k, and IOG for the corresponding sites and components. Needless to say, the imaginary part of Green function (IOG) is closely related to the amplification characteristics of the objective site.

Using these theory, Zhang et al. focused on the power-spectral density function of respective sites A and O for the vertical component, SAA(ω) and SOO(ω), and took the ratio of them to eliminate the unknown factors Es and k. They showed the predominant period (TIOG) of the ratio of IOGs (RIOG) reflects the geological profile of the two sites by numerical study using two layered model, the layer boundary of which is linearly sloped.

However, the applicability of the technique to actual microtremor data was still unclear, because not only the subsurface structure is more complicated in actual site but observed microtremor data inevitably includes various types of noise, and these facts necessarily effect on RIOG in some way.

To confirm the applicability of the technique using RIOG to actual data, we conducted microtremor array observations over the ground surface, the bedrock surface of which is considered to being steeply sloped, and evaluated the subsurface structure using RIOG and RH/V. With respect to RIOG, we focused on the difference between TIOGs (ΔTIOG) which was calculated for the different pair of RIOG, to evaluate the relative difference in thickness of the subsurface layer between the two sites.

Although both RIOG and RH/V basically seemed to be complicated, the following states were found; It is difficult to find the corresponding peak to the engineering bedrock from RH/V and there are almost no differences between TH/Vs for different observation point. On the other hand, the ΔTIOG gradually change with the location of observation points. These results indicate the applicability of RIOG to an irregular ground.

A future work is to establish the method to estimate absolute thickness of surface layer. It is necessary to investigate the relationship between ΔTIOG and the amount of change in the depth of sloped-engineering bedrock by numerical study.

Keywords: Irregular ground, Imaginary part of Green function, estimation of velocity structure