Structure Health Monitoring Experiment of 10-stories RC building applying i-Jishin

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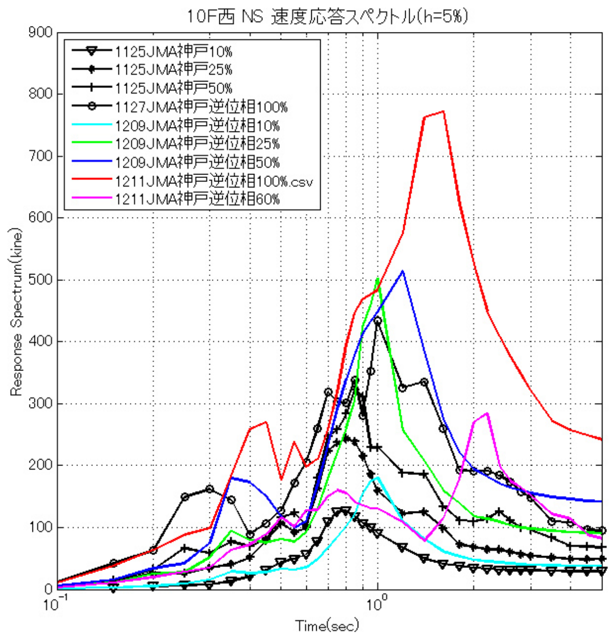
i-Jishin cloud system is a disaster prevention sensor cloud system consisting of a free iOS app "i-Jishin" and Web services "Geonavi / icomi". In order to evaluate the applicability of this system for Structual Health Monitoring, it was carried out vibration experiments of 10 layers of RC structures on E-Defense in November-December 2015.
This article does not addressed until more information about the earthquake disaster determination method based on the system, we describe to the state estimated by the data acquisition and building response spectra up to the previous diagnosis.
Experimental methods: Method of the experiment is as follows.
- We attached two iOS terminals installed i-Jishin on the wall of each 10,6,5,1 layer of the RC structure test body, and uploaded the data to icomi via wireless LAN.
- We carried out shaking test held four days of the 2015, on November 25th, 27th, December 9th and 11th, measured microtremor in the same position of the i-Jishin installation floors prior and subsequent to each shake.
- Measurement parameters of i-Jishin were trigger setting 30 gal, trigger duration 2s, pre-trigger 20s, post-trigger 60s.
- As analysis of the acquired data by the MEMS acceleration sensor, seismic intensity, response spectrum (acceleration, velocity, displacement) were calculated respectively.
Result of the experiment: The experimental results are as follows.
- A dominant period prolongation of response spectrum was observed corresponds to the input ground motion.
- This is roughly consistent with the measurement results of the microtremor former and latter the shake.
- Success rate of the data uploaded by the mobile line was 93 percent.
Although structural health monitoring (SHM) systems using acceleration sensors are operating for commercial bases on the high-rise buildings, valuable data obtained are not shared for disaster prevention research for privacy reasons. There is a problem of trade-off between reliability and cost.
This experiment showed possibility to evaluate damage of the medium-sized apartments by earthquake with smartphone’s accelerometer. If it is possible, it can be regarded as an easy and powerful disaster prevention tool at a low cost that contributes to the rapid ensuring safety at the time of disaster. It is still insufficient to allow the disaster judgment in the instant, but state estimation of the structure is possible immediately.

Keywords: SHM, Sensor Cloud, mobile terminal, i-Jishin, E-Defense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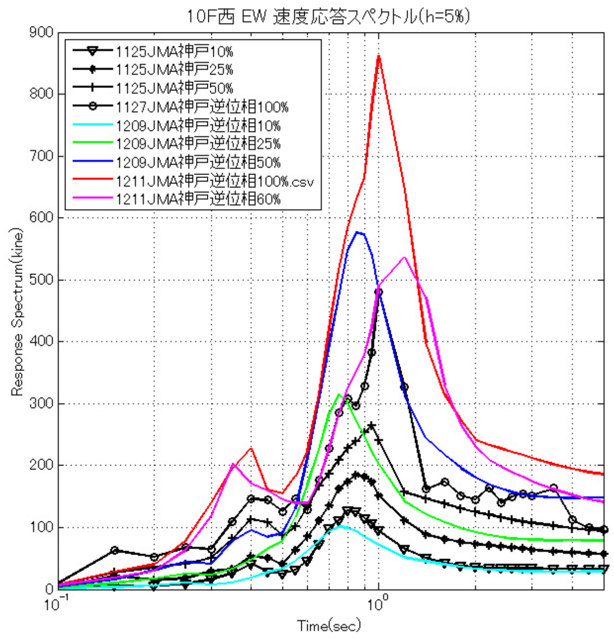
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Potential for Monitoring Earth Activities using Optical Fiber Network and DAS (Distributed Acoustic Sensing) Technology

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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 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, while the maximum length is reduced to around 10km for MMF with current system, depending on the level of optical signal loss and optical sampling frequency.
Conventional electro-magnetic seismic sensors have been installed all over the places in Japan, especially after the Tohoku earthquake and tsunami in 2011, however, the measurement of the conventional sensors are point basis, while installation cost and environmental ratings of the conventional sensors limits the number and location of the sensor installations.
In case of hDVS/DAS system, any existing optical fiber installations, which have been used for data transmission purpose mainly, would become line shaped seismic sensor instantly. This fact allows installation cost and time minimized. As a part of the IT Revolutions last 20 years, there have been built the network of optical fibers across Japan and over the ocean between Japan and US or other Asian countries. Especially, the international ocean bottom optical fiber cables were installed over the Seismogenic areas. If the ocean bottom cables would become seismic sensor instantly, how would you like to use the data?
In terms of environmental specification of optical fiber, the core part is made of high-silica glass, so that high temperature version of optical fiber is widely available over 200 degC where conventional sensors cannot be installed. There are 500 degC or even higher the temperature rating fibers are available using special coating materials. It means optical fiber sensor would potentially be installed near the Seismogenic layers in deep wells, which would allow real-time seismic activity monitoring with speed of light.
hDVS/DAS technology would potentially allow us to have comprehensive real-time monitoring network on surface, ocean bottom or subsurface of Japan without requiring high cost and time in order to minimize loss of human life and our lovely heritages during upcoming events which we cannot eliminate.
During the presentation, overview of hDVS/DAS system and examples of seismic data recorded during Field trials last few years will be explained, followed by vision of Earth Activities monitoring network in Japan.

Keywords: DAS, hDVS, Optical Fiber Network, Earthquake Monitoring, Seismic

A simple velocity model for hypocenter determinations using data from land and ocean observation networks

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Introduction:
In order to improve detection capabilities of earthquakes in the ocean, dense observation networks as DONET by JAMSTEC and S-net by NIED have been developing in recent years. Hypocenter determinations using data from these networks and land observation data will improve the accuracy of earthquake source locations in the ocean. On the other hand, 1D velocity structure may not be appropriate because of strong lateral heterogeneities in subduction zones. Nakano et al. (2015) used 3D velocity model for hypocenter determinations. But this method is not appropriate for real-time or routine operations because of its high computational cost.
In this study, we propose a simple 2D velocity model for hypocenter determinations using data from ocean and land observation networks.
Proposed velocity model:
We propose a 2D model of which 1D velocity structures of land and ocean are connected along a plate boundary. The ray path is assumed not to bend in the horizontal direction. For hypocenter determinations, a travel time table with respect to the source depth, epicentral distance, and the depth where the ray path crosses the plate boundary. The plate boundary is defined according to the hypocenter distribution determined by JMA. The boundary is separated to several segments to represent horizontal bending of the plate boundary.
The proposed velocity model is 2D, but it resembles 3D plate model because we have incorporated horizontal plate bending. The implementation is easy because the travel times can be computed using 1D ray tracings.
Hypocenter determinations:
Using the 2D model proposed above, and 1D models assuming land and ocean, we determined hypocenters. We estimated site corrections for the P- and S-wave travel times for each station, and re-determined the hypocenters. We used P- and S- readings from DONET1 and land stations used in Nakano et al. (2015).
Epicenter distributions are almost the same for the three models, but the source depths are distinctly different: 1D land model overestimates the source depths in the ocean.
At stations in the ocean, the obtained site corrections reflect the thickness of the sediments in the basin, a common feature obtained for the three models. At stations on land, we obtained corrections larger than 1 s for 1D ocean model. Correction values were rather small for 1D land and 2D models on land.
The RMS traveltime residual was 0.45 s, 0.52 s, and 0.46 s for 1D land, 1D ocean, and 2D models, respectively.
Discussion:
The RMS traveltime residual indicate that the 1D land model explains the observed ones as well as the 2D model proposed, while the source depths are overestimated. To explain this feature, we conducted the same analysis above but using data from only DONET stations and earthquakes that occurred beneath the sea for the 1D land and ocean models.
Hypocenter distributions were almost same including the source depths, giving almost similar RMS residuals of about 0.25 s. The site corrections, on the other hand, were very different: For the 1D land model, the corrections for P and S waves were positive (to delay observed one) and negative,

respectively, at almost all stations. This result indicates that setting uniform corrections for travel times compensated the mismatch of the velocity structure.
From this result, we obtained the conclusion that the overestimation of the source depths for 1D land model using ocean and land data was due to compensations of the late travel times for earthquakes in in the ocean, without much degrading the RMS residuals.
Conclusion:
Use of an accurate velocity structure is necessary for appropriate estimations of earthquake source depth, which is crucial for discussions of seismic activities in the ocean and evaluations for tsunami potential. The 2D model proposed in this study would be appropriate especially for real-time source determinations.

Keywords: DONET, S-net, Subduction zone

Array observation of strong ground motion for the estimation of current wavefield in real time

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We aim to construct next generation of Earthquake Early Warning (EEW) system with (a) grasp of current wavefield in real time using data assimilation technique and (b) real-time ground motion simulation with current wavefield as an initial condition.

In Hoshiba and Aoki (2015), they used an amplitude distribution of dense seismic network to estimate the current wavefield. However, other observation value should be able to use for estimating current wavefield. Array observation can reveal slowness vector of the wavefield at the observation site. To utilize the array observation for the EEW system, we construct an array network using six acceleration seismometers and conduct some studies using them. Our array size is less than 300 m so that we use 500 Hz for sampling frequency.

Here we adopted semblance analysis (Neidell and Taner, 1971) for estimating slowness vector. Real-time (less than 1 s) semblance calculation is required for making use of analysis result for the EEW system. Oct-tree search (Lomax et al., 2009) enabled us to calculate slowness vector within 1 s using time window of 4 s of 6 stations.

Comparison of estimated backazimuth values and those from the earthquake catalogue showed that backazimuth residual had clear azimuthal dependency. This feature could be explained by the dipping layer beneath the array, and estimated backazimuth values became consistent with those of catalog values through dipping layer correction (Niazi, 1966; Maki et al., 1987).

In addition to the evaluation of estimated slowness vector, we have considered that how the estimated slowness vector affects to the EEW system. In a simple 2-D case, backazimuth information prevents the underprediction of seismic ground motion in the early stage of prediction (i.e. seismic waves have arrived in only one or a few stations). We will further discuss the effects of array observation to the EEW system through some numerical simulations.

Keywords: Earthquake Early Warning, Array observation, real-time calculation

Improvement of Epicentral Direction Estimation by P-wave Polarization Analysis

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Polarization analysis has been used to analyze the polarization characteristics of waves and developed in various spheres, for example, electromagnetics, optics, and seismology. As for seismology, polarization analysis is used to discriminate seismic phases or to enhance specific phase (e.g., Flinn, 1965)[1], by taking advantage of the difference in polarization characteristics of seismic phases.
In earthquake early warning, polarization analysis is used to estimate the epicentral direction using single station, based on the polarization direction of P-wave portion in seismic records (e.g., Smart and Sproules(1981) [2], Noda et al.,(2012) [3]). Therefore, improvement of the Estimation of Epicentral Direction by Polarization Analysis (EEDPA) directly leads to enhance the accuracy and promptness of earthquake early warning.
In this study, the author tried to improve EEDPA by using seismic records of events occurred around Japan from 2003 to 2013. The author selected the events that satisfy following conditions.
1) MJMA larger than 6.5 (JMA: Japan Meteorological Agency).
2) Seismic records are available at least 3 stations within 300km in
epicentral distance.
Seismic records obtained at stations with no information on seismometer orientation were excluded, so that precise and quantitative evaluation of accuracy of EEDPA becomes possible. In the analysis, polarization has calculated by Vidale(1986) [4] that extended the method proposed by Montalbetti and Kanasewich(1970)[5] to use analytical signal.
As a result of the analysis, the author found that accuracy of EEDPA improves by about 15% if velocity records, not displacement records, are used contrary to the author’s expectation. Use of velocity records enables reduction of CPU time in integration of seismic records and improvement in promptness of EEDPA, although this analysis is still rough and further scrutiny is essential.
At this moment, the author used seismic records that obtained by simply integrating acceleration records and applied no filtering. Further study on optimal type of filter and its application frequency band is necessary.
In the presentation, the results of aforementioned study shall be shown.

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Keywords: polarization analysis, estimation of epicentral direction, earthquake early warning

Rapid detection of early aftershocks using high-frequency seismogram envelope: improvement of location estimation of energy radiation point

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Because waveforms of many early aftershocks are overlapped in seismograms, conventional hypocenter determination technique based on the picking of P and S wave arrival times does not work well at the early lapse times after a large earthquake. On the other hand, real-time forecasting of aftershock activity requires sufficient amount of aftershock data in the early lapse times. Sawazaki and Enescu (2014) developed the envelope inversion method that can rapidly detect the energy radiation rate from the early aftershock sequence. In their method, propagation of high-frequency (>1Hz) seismic energy is considered to follow the radiative transfer theory, and the observed seismogram envelopes are regarded as the convolution of energy radiation and propagation processes. To locate the energy radiation point, they compute the sum of squared residual between the observed and the theoretical peak amplitude of the envelopes, and search the minimum residual point at each discrete time step. However, because the theoretical envelope synthesized based on the radiative transfer theory cannot describe both the peak arrival time and the peak amplitude well, the detected energy radiation point frequently has a large error. In this study, I synthesize the theoretical envelope based on the forward scattering approximation that can better describe the peak arrival time and the peak amplitude, and use this in combination with the conventional radiative transfer-based envelope to improve location estimation of the energy radiation point. The hybrid envelope used in this study includes not only S wave but also P wave energies because the amplitude of P wave is sometimes comparable to that of S wave and should not be neglected. I examine seismogram envelopes of 8-16 Hz that are recorded by 13 Hi-net and KiK-net stations located within 70 km from the hypocenter of the 2008 Iwate-Miyagi Nairiku earthquake (M_{JMA}7.2). In total 91 aftershocks which satisfy M_{JMA}>3.4 are detected within half day after the mainshock according to the JMA unified hypocenter catalog. I first perform the conventional detection method that uses the radiative transfer-based envelope, and find that 10 of the 91 aftershocks are located over 20 km apart from the corresponding JMA hypocenters. Next I perform the new detection method that uses the hybrid theoretical envelope, and find that the number of the corresponding aftershocks reduces to one.

Keywords: detection of early aftershocks, analysis of high-frequency envelope

Real-time Earthquake Magnitude Estimation by Real-time GNSS positioning: the development of GEONET real-time processing system, REGARD

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The displacement data produced by GNSS observations never saturate for large earthquakes in contrast to seismometer data that has a limitation of instrument saturation. Recently, many researches recommends to utilize GNSS real-time kinematic analysis for rapid real-time earthquake magnitude estimations that improve tsunami forecasts (e.g., Blewitt et al., 2009; Ohta et al., 2012). This fact actively forward GNSS real-time analysis for disaster preventions after the 2011 Tohoku Earthquake. For example, READI project has started in western U.S. by a team of several universities and agencies which operate GNSS network to advance tsunami forecasts. The International Union of Geodesy and Geophysics 2015 resolved to engage with IUGG member states to promote a GNSS augmentation to the tsunami warning systems. Geospatial Information Authority of Japan, which operates Japan’s national GNSS network GEONET including ~1300 sites, has also launched a project to develop a system that estimates earthquake fault model rapidly using GNSS data in collaboration with the Tohoku University. The system is named REGARD: Real-time GEONET Analysis system for Rapid Deformation monitoring.
In this paper, we show the overview of REGARD and assess the performance of REGARD for the previous large earthquakes. We used the data of four previous large earthquakes occurred on plate boundaries around Japan: 2003 Tokachi-oki earthquake, 2011 Tohoku earthquake and the largest after shock, Ibaraki-oki earthquake. The simulation data of the 1707 Hoei type Nankai trough earthquake (Todoriki, 2013) was also used. The Mw estimates with high variance reductions > 90 % were derived for all the earthquakes within 3 minutes. It is noteworthy that the Mw 8.83 was estimated for the 2011 Tohoku earthquake by 3 minutes without saturations. The performance assessment of REGARD confirmed that the real-time GNSS analysis is very powerful to estimate reliable Mw for large earthquakes with M > 8 rapidly. Future work will involve the improvement of GNSS analysis with multi-GNSS, PPP, etc. to provide more stable fault models.

Keywords: RTK GNSS, Real-time fault model estimation, GNSS seismology

Improvement of Real-time GEONET Analysis System for Rapid Deformation Monitoring, REGARD

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Geospatial Information Authority of Japan (GSI) has been operating a continuous GNSS observation network system since 1994. This system is known as GEONET (GNSS Earth Observation Network) and consists of approximately 1300 nationwide GNSS stations (GEONET stations) and the analysis center. Most stations collect GNSS data with 1-Hz sampling and transfer them to the analysis center in real time. Those data are available for surveying or research using real-time kinematic positioning technique. This technique is expected for describing cataclysmic earthquake from crustal displacement in short time especially after the 2011 off the Pacific Coast of Tohoku Earthquake in March 2011.
GSI and Tohoku University have developed the Real-time GEONET Analysis System for Rapid Deformation Monitoring (REGARD) since September 2011 to estimate moment magnitudes (Mw) soon after large earthquakes struck. This system consists of three subsystems. First subsystem does real-time kinematic positioning using RTKLIB (Takasu, 2013) and GSILIB (GSI, 2015). Second one detects seismogenic behavior using the RAPiD algorithm (Ohta et al., 2012) or the Earthquake Early Warning (Kamigaichi et al., 2009) and immediately run the third subsystem. This subsystem estimates Mw within three minutes using displacement vectors of GEONET stations (Kawamoto et al., 2014). Finally, results are mailed to persons involved.
Last year, we expanded its function of real-time kinematic positioning by using multi-GNSS and enhanced its redundancy by carrying out independent processing in parallel. We introduced three fixed points in Hokkaido, Hokuriku and Kyushu districts to monitor kinematic baseline solutions, respectively. We also improved the browser used in the agency to search for previous results and visually recognize results of the real-time kinematic positioning.
In this presentation, we report the overview and the current situation of REGARD, including the operational results.

Keywords: GEONET, RTK-GPS, real-time

Eruption Notice -information urging people to take swift and appropriate protective action

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JMA monitors volcanic phenomena of all the 110 active volcanoes in Japan, evaluates the status of the volcanoes, and issues Volcanic Warnings for them to mitigate the effects of volcanic disasters. When life-threatening phenomena (such as ballistic projectiles and pyroclastic flows) and/or extension of the affected area by the phenomena are expected, JMA issues the Warnings together with target areas where action for disaster mitigation is needed. For volcanoes where Volcanic Alert Levels are in effect, JMA issues Warnings with Alert Levels that are in line with disaster mitigation actions pre-agreed at the relevant local Volcanic Disaster Management Council. Once issued, the Warnings are immediately transmitted to the residents through municipalities concerned as well as mass media. Disaster management organs in the municipalities then take necessary actions such as setting restricted areas and/or evacuation orders.
At the eruption of Ontakesan (Mt. Ontake) on 27 September 2014, JMA issued the first observation report 8 minutes after the eruption. JMA then investigated the eruption details including target areas and issued the first Volcanic Warning 44 minutes after the eruption. However, the eruption killed many climbers around the crater. Study Group on the Provision of Volcano Information under the Coordinating Committee for Prediction of Volcanic Eruption recommended JMA to establish new information which notifies people entering volcanic areas of an eruption immediately in an easy-to-understand manner so that they can take swift protective action. JMA launched the Eruption Notice system on August 2015.
Eruption Notices are issued right after a volcanic eruption is detected. The Notices report only the occurrence of an eruption before evaluating its magnitude to urge climbers and residents around the volcano to take swift protective action. Eruption Notices are issued for volcanoes with continuous monitoring when eruptions occur after a period of inactivity or those on an unprecedented scale. Even when plumes are not identified in visual observations due to bad weather, JMA issues a Notice with supplementary statement “eruptions are thought to have occurred” if an eruption is presumed from seismometer and/or low-frequency microphone data.
Eruption Notices are provided via TV, radio and mobile phones as well as JMA website. As of January 2016, information providing services using mobile apps and e-mails are available from the following three companies: Yahoo! JAPAN, Japan Meteorological Cooperation and WEATHERNEWS INC.

Keywords: eruption, notice, protective action

Retrospective evaluation of tFISH/RAPiD performance: tsunami forecasting based on offshore tsunami and GNSS data

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tFISH (Tsushima et al., 2009) is an algorithm for real-time tsunami forecast that inverts the waveform data recorded offshore to estimate the distribution of the initial sea-surface height, synthesizes tsunami waveforms at coastal tide-gauge stations.
We have been made a retrospective evaluation of tFISH based on the offshore tsunami data of the Sanriku-oki earthquake (Mw7.3) occurred on March 9, 2011, the largest foreshock of the 2011 Tohoku-oki earthquake. By comparing the calculated waveforms with observations, it was confirmed that the coastal tsunami waveforms obtained by tFISH agree well to the observations ~ 6 min after the earthquake, or ~ 25 min before the arrival of the first wave to the coast. However, it is difficult to estimate the initial sea surface height accurately by the offshore tsunami data immediately after the earthquake, and the inaccuracy caused significant underestimation of forecasted tsunami heights along the coast.
In this study we test tFISH/RAPiD (Tsushima et al., 2014) that incorporates RAPiD algorithm (Ohta et al., 2012) into the coastal tsunami forecasting based on the tsunami waveforms synthesized by using a real-time estimated tsunami source model, with using the GNSS data obtained during the same earthquake, as well as the offshore tsunami waveforms.
The onshore GNSS data of GEONET operated by Geospatial Information Authority of Japan (GSI) are available in real time and it is expected that a source model of an M-7 class earthquake can be obtained within ~ 3 min after the earthquake occurrence, giving the initial sea surface height distribution for the tsunami computation, a RAPiD solution. In tFISH/RAPiD, a RAPiD solution is used as a starting model for tsunami forecasting, and then the tsunami source model is iteratively improved with time by including the tsunami waveforms observed at offshore stations into the source estimation.
Our results show that the RAPiD solution obtained after the M 7.3 earthquake provided the coastal tsunami waveforms agree fairly well to the observations and the forecasting based on the real-time geodetic data complement the very early tsunami forecasting. We note here that our test proves that tFISH/RAPiD would work even for M-7 class inter plate earthquakes, much smaller than the case previously tested.
The good agreement of the tsunami waveforms based on the RAPiD solution to the observations further suggests that the tsunami calculation based on the onshore geodetic data can provide a valuable information for early coastal tsunami forecasting, when there are no offshore stations near the source area and tFISH would not work well.

Keywords: Near-field tsunami forecasting, ocean-bottom pressure gauge, tsunami waveform inversion

A forward analysis approach using ocean-bottom pressure data for real-time tsunami forecast

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We developed real-time tsunami forecast methods using only ocean-bottom pressure data from a dense offshore observation network without inversion analyses, which can yield large uncertainties (Aoi et al., 2015, AGU). We propose a rapid and simple method of estimating the approximate tsunami source location using offshore ocean-bottom pressure data and multi-index method to rapidly match between offshore tsunami observations and pre-calculated offshore tsunami waveforms (Yamamoto et al., 2014, AGU; Suzuki et al., 2015, JpGU; Yamamoto et al., 2015, AGU). In these studies, a set of about 2,000 tsunami scenarios prepared for a research project of nationwide probabilistic tsunami hazard assessment for Japan (Hirata et al., 2014, AGU) are used, because they consider any possible tsunami sources that may affect the Pacific coast of Japan. The tsunami waveforms at locations of the Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net) and maximum coastal tsunami heights along the Pacific coasts of Japan are calculated. These data are registered in the proposed Tsunami Scenario Bank (TSB).
To estimate the approximate tsunami source location, we define the tsunami centroid location (TCL), which is the centroid location of the maximum absolute amplitude of the real-time ocean-bottom hydrostatic pressure changes. To determine whether the TCL can approximate the tsunami source location, which is assumed to the centroid location of the absolute values of the initial sea surface height displacements, we examine approximately 1,000 near-field synthetic tsunami scenarios and a realistic tsunami scenario of the 2011 Tohoku earthquake. From these examinations, we confirm that in most scenarios, the TCLs obtained within a few minutes after an earthquake occurrence are close to the corresponding tsunami source locations.
To quickly select dozens of appropriate tsunami scenarios that can explain the offshore observations, we use multiple indices. The key feature of the method is a rapid matching between offshore tsunami observations and pre-calculated offshore tsunami waveforms. We apply three indices, which are the correlation coefficient and two kinds of variance reductions normalized by the L2-norm of either the observed or calculated waveform, to match the observed waveforms with the pre-calculated waveforms in the TSB. To examine whether our method can select appropriate tsunami scenarios, we conduct synthetic tests using “pseudo observations.'' Based on the test results, we confirm that the method can select appropriate tsunami scenarios within a certain precision by using the two kinds of variance reductions, which are sensitive to the tsunami size, and the correlation coefficient, which is sensitive to the tsunami source location. At the same time, the coastal tsunami information coupled with the selected tsunami scenarios are forecast.
This work was supported in part by the Council for Science, Technology and Innovation (CSTI) through the Cross-ministerial Strategic Innovation Promotion Program (SIP), entitled ``Enhancement of societal resiliency against natural disasters'' (Funding agency: JST).

Keywords: Tsunami, Real-time prediction, S-net

Tsunami simulation method initiated from waveforms observed by ocean bottom pressure sensors for real-time tsunami forecast; Applied for 2011 Tohoku-oki Tsunami

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After tsunami disaster due to the 2011 Tohoku-oki great earthquake, improvement of the tsunami forecast has been an urgent issue in Japan. National Institute of Disaster Prevention is installing a cable network system of earthquake and tsunami observation (S-NET) at the ocean bottom along the Japan and Kurile trench. This cable system includes 125 pressure sensors (tsunami meters) which are separated by 30 km. This system is the most dense observation network system on top of source areas of great underthrust earthquakes in the world.
Real-time tsunami forecast has depended on estimation of earthquake parameters, such as epicenter, depth, and magnitude of earthquakes. Recently, tsunami forecast method has been developed using the estimation of tsunami source from tsunami waveforms observed at the ocean bottom pressure sensors. However, when we have many pressure sensors separated by 30km on top of the source area, we do not need to estimate the tsunami source or earthquake source to compute tsunami. Instead, we can initiate a tsunami simulation from those dense tsunami observed data. We have already presented a method at the 2015 SSJ meeting. Observed tsunami height differences with a time interval at the ocean bottom pressure sensors separated by 30 km were used to estimate tsunami height distribution at a particular time. Tsunami numerical simulation was initiated from tsunami height distribution. We demonstrated that the method worked well for case studies.
In this paper, the above method is improved and applied for the tsunami generated by the 2011 Tohoku-oki great earthquake. Tsunami source model of the 2011 Tohoku-oki great earthquake estimated using observed tsunami waveforms, coseimic deformation observed by GPS and ocean bottom sensors by Gusman et al. (2012) is used in this study. The ocean surface deformation is computed from the source model and used as an initial condition of tsunami simulation. Linear long wave equations are solved by finite difference scheme. A grid size is 1 min. (about 1.8 km). Figure (left) shows the computed tsunami height distribution at 10 minutes after the earthquake. By assuming that this computed tsunami is a real tsunami and observed at ocean bottom sensors, new tsunami simulation is carried out using the above method. The station distribution (each station is separated by 15 min., about 30 km) observed tsunami waveforms which were actually computed from the source model as an experiment is shown in Figure (right) as red dots. Tsunami height distributions are estimated from the above method at 40, 80, and 120 seconds after the origin time of the earthquake. After interpolation of these tsunami height distribution into a 1 minute grid system, the tsunami numerical simulation is carried out using those tsunami height distribution. Tsunami height distribution computed from the source model includes large short wavelength waves which are originally generated near the trench (see Figure). This is one of important characteristics of the 2011 Tohoku-oki tsunami. However, observed points separated by 30 km are too coarse to describe such a short wavelength wave. Therefore, that causes some error in the overall tsunami height distribution. Also, because this method uses the observed height differences with a time interval as data, a resolution of very long wavelength is low. In this paper, we improve the method by applying a special filter to the estimated tsunami height distribution from the observed tsunami waveforms separated by 30km in order to obtain a stable solution. The tsunami height distribution at 10 minutes after the earthquake estimated from the new method is shown in Figure (right). Comparison between Figure (left) and Figure (right) shows that generally the method works well. The

method developed in this paper is effective as a real-time tsunami forecast.

Keywords: Real time tsunami forecast, Tsunami simulation method, The 2011 Tohoku-oki Tsunami