Rapid Earthquake Magnitude Detemination with Strain Analysis on Fourier Domain

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In order to apply observation records in the field of natural science to disaster prevention, it is important to increase the accuracy of information. For this purpose, it is important to reference many results that derived from different observed diversely. In this study, we developed new earthquake magnitude estimation method by using dynamic strain records to contribute the improvement of RAPiD (*e.g.*, Ohta *et al.*, 2012). In this method, extract deformations purely affected by source process by strain analysis in the frequency domain. And by re-synthesizing source time function and moment release function from these strain spectra, the scalar moment will be obtained.
Strainmeter is a crustal deformation observational instrument detects deformation that is the spatial differential of displacement, which will be observed by GNSS. Strainmeters' responses can be improve up to higher frequency range (20Hz ~) adept for seismic ground motional deformation, because those mechanism of strainmeter is quite simple.
Dynamic strain analysis for seismic motions to understand source process of a great earthquake is being made taking advantage of these frequency responses of strainmeter (Okubo *et al.*, 2007; JpGU, Okubo, 2007; TRIES report). Generally, plane strain analysis requires three observational components on the same plane. If we could use observatories have more than four horizontal components, we can extract the principal strain amplitudes, those azimuth and observational errors from strain records (Okubo, 2005; SSJ). Additionally, strain analysis can also be applied to spectra in frequency domain, converted from strain records (Okubo, 2007; SSJ). Strain analysis in the frequency domain (Fourier Strain Analysis; FSA), is possible to separate very long period variations and influence of disturbance near the observatory. Since strain is a spatial distribution, it can be easily affected by fluctuations strongly dependent on observatory such as responses for precipitation and groundwater level change. Thus we require a systematic approach to eliminate those undisireable variations.

Keywords: Fourier Strain Analysis, Scalar Moment, Multi Components borehole strain meter

W-phase analysis by using high-sampling-rate (1Hz) GNSS data (for the case of the 2016 Kumamoto earthquake)

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To research a focal mechanism of the large earthquake immediately in addition to its magnitude is very important for issuing an alert for evacuation. Especially the height of tsunami with the earthquake in coastal areas varies awfully with its focal mechanism. For appropriate tsunami alert issuing, Japan Meteorological Agency is performing W-phase analysis using broadband seismometers in order to obtain a focal mechanism of the earthquake (Usui and Yamauchi, 2013).
Ueno et al.(2014) and Miyaoka et al. (2015, 2016) tried W-phase analysis using high-rate sampling(1Hz) GNSS data for the 2003 Tokachi-Oki earthquake(Mw8.0), the 2011 Tohoku-Oki earthquake(Mw9.0) and its largest aftershock(Mw7.7), then CMT solutions were determined precisely. There are some advantages in using GNSS data for the W-phase analysis that we can use a great number of high dense GNSS network data operated by GSI in Japan and perform the analysis without a translation process from velocity data to displacement data which is required in the analysis using broadband seismometers.
The usefulness of this analysis method for the great earthquakes (M>=8) has been already confirmed (Miyaoka et al., 2016), furthermore we attempted to apply this method to smaller earthquakes in this study. We analyzed the mainshock in the 2016 Kumamoto earthquakes (01:25 on April 16, 2016, Mj7.3) using relatively low-frequency-band (100-300sec) and near-field stations (within 3°). As a result, we obtained a similar focal mechanism solution with GCMT by USGS.
In the presentation, we would like to show results of the analysis for the 2016 Kumamoto earthquake and also for the Off Fukushima earthquake (05:59 on November 22, 2016, Mj7.4).

Keywords: W-phase, high-sampling-rate GNSS data, Kumamoto earthquake

Potential for Real-Time Earthquake Monitoring using Optical Fiber Network and DAS Technology

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During the JpGU 2016, I introduced that DAS (Distributed Acoustic Sensing) technology was introduced in 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).

Unlike conventional seismic recording system, which usually use electro-magnetic sensor or Geophone, hDVS 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 use.

Conventional electro-magnetic seismic sensors have been installed all over the places in Japan after the Great Hanshin earthquake in 1995, and then the network has been expanded including ocean bottom after the Tohoku earthquake and tsunami in 2011. The earthquake monitoring network in Japan is indeed the densest in the world. 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 addition, it has been concerned about the damage of the existing monitoring network hit by a mega earthquake in the future, and then the continuous monitoring would be affected when needed.

In case of hDVS system, any existing optical fiber installations, which have been used for data transmission purpose mainly, would become line shaped seismic sensor. This fact allows installation cost and time minimized. As a part of the IT Revolutions, there have been built the network of optical fibers across Japan and over the ocean between Japan and US or other Asian countries. Since the international ocean bottom optical fiber cables were installed over the seismogenic areas where the boundaries of the plates existing, by using an hDVS system it would be possible to monitor the activities of the plates several tens of kilometers of distance in real-time.

The environmental specifications of optical fiber, 200 degC or even much higher the temperature ratings and over 200,000psi pressure ratings, optical fiber sensor would potentially be installed near the Seismogenic layers in deep wells or near volcanos, which would allow real-time seismic activity monitoring with speed of light.

In addition to the existing earthquake monitoring network, hDVS technology would potentially allow us to have comprehensive real-time monitoring network with speed of light on surface, ocean bottom or subsurface of Japan, where no sensor is available, without requiring high cost and time. Using such comprehensive monitoring network, it is believed that loss of human life would be minimized from upcoming events which we cannot eliminate.

Keywords: DAS, hDVS, optical fiber, earthquake, seismic, real-time monitoring

Optimization of offshore tsunami meter network using Green function.

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Nowadays, a tsunami waveform inversion plays a major role not only for scientific purposes, such as to determine the initial sea level change, but also for a practical application of tsunami disaster prevention. The effectiveness of the offshore tsunami meter has been long recognized for the tsunami inversion. The tsunami inversion using offshore tsunami meter network and the tsunami inversion has been the a popular subject in tsunami science. Japan is not the largest tsunami-affected country in the world, but it has one of the most advanced technologies in relation with the tsunami disaster prevention. Japan has been affected by many tsunami disasters in history, but the number of victims of each tsunami was about tens of thousands or so, owing to the well-established tsunami observing systems. In contrast, the o 2004 Sumatra island Tsunami (December 26, 2004 M9.1) killed approximately 230 thousand people in Indonesia being the largest damaged country, in which the number of the victims was about ten times of the 311 Tohoku tsunami. Unfortunately, it may be difficult for a developing country to develop a tsunami observation system equivalent to S-net independently, considering Indonesia's GDP is only 1/5 of Japan’s. If an offshore tsunami observation system is designed at costs of 1/5 of S-net, it can contribute to many tsunami-affectable countries. Several approaches and methods such as data resolution matrix have been studied as an objective method for optimally placing observation points using a linear inversion through the Green function. Furthermore, the amount of information obtained at each observation point can be increased by including flow velocity components. Therefore, we can achieved more accurate results using less observation points leading to the significant cost reduction. In this research, we present the result of virtual observation networks placed off Sanriku sea region. We conclude that by using three observed components (elevation, u, v) and data resolution matrix, we can properly assess the effectiveness of observation points which are equipped three component meters; located above the wave source; expanded from the Japan Trench to the Pacific Ocean.

Keywords: tsunami, inversion, observation network, optimization

Development of semi-real-time tsunami monitoring and calculation system for pressure gauge stations in southwestern Japan

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Ocean-bottom observatory systems provide powerful means to monitor geophysical phenomena in ocean areas, such as seismic activity, geodetic deformations, submarine eruptions and landslides, turbidity and bottom currents, tides, and tsunamis. Such observations develop our understanding of the dynamics of the Earth through the ocean. In 2011, JAMSTEC (Japan Agency for Marine–Earth Science and Technology) deployed 20 sets of ocean-bottom stations, namely DONET1 (Dense Oceanfloor Network System for Earthquakes and Tsunamis), in water depths of 1,900–4,400 m off the Kii Peninsula in southwestern Japan (Kawaguchi et al., 2011, 2015; Kaneda et al., 2015). In 2016, JAMSTEC also deployed 31 sets of stations, DONET2, in water depths of 1,100–4,400 m on the western side off the Kii peninsula. We refer to these ocean-bottom observatory systems, DONET1 and 2, as "DONET". Each station in DONET has strong-motion and broadband seismometers, hydrophones, differential and quartz pressure gauges, and thermometers. DONET pressure sensor data are expected to be useful for detecting tsunamis and for issuing tsunami warnings as reviewed by Rabinovich and Eblé (2015).

In this study, we developed a semi-real-time calculation and data monitoring system that measures pressure perturbations at the DONET pressure-gauge stations in order to identify tsunami signals associated with earthquakes (Nakamura and Baba, 2016). The system automatically calculates geodetic deformations and tsunami propagation immediately after getting seismic source information on hypocenter, magnitude, and mechanism. We use the list of point source mechanisms from the Global Centroid Moment Tensor (Global CMT) solution (Dziewonski et al., 1981; Ekström et al., 2012). The rupture duration and the fault size are estimated from the seismic moment via a scaling law. We implemented a hybrid MPI/OpenMP parallelization into the code to enable efficient parallel computation. The code was optimized by paying careful attention to the order in which elements in array variables are accessed, avoiding subroutine calls in the innermost loop iteration, and avoiding the use of unnecessary conditional branches in loop iterations, where processors spend much time.

The calculation results for transoceanic tsunamis can be available in approximately 20 s after getting source information to output waveform data by executing the optimized parallel calculation code on our computer server SGI UV2000 with a 32-core processor unit. The system also provides tide-removed and filtered waveform data at ocean-bottom stations, enabling the calculation results to be compared with actual tsunami arrivals. System operations began in July 2015 and have been applied to tsunamigenic earthquakes in the Pacific Ocean. At the 2015 Illapel, Chile, earthquake (Mw 8.2), the calculated waveforms show a good reproduction for the observations. At the 2015 earthquake (Mw 6.8) off the west coast of southwestern Japan, the calculated waveforms show the maximum tsunami amplitude of 0.3 mm, indicating quantitatively that tsunamis at the DONET pressure-gauge stations are of lower amplitude than the noise levels of the observations. These results demonstrate that the system is effective in identifying tsunami signals and automatically predicting tsunami propagation in offshore areas, which may be useful for further data analyses on tsunami propagation.

Keywords: tsunami, DONET, pressure gauge, early warning

Development of manual picking system of seismic wave correcting accurate automatic pickings

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1. Introduction
We have been developing P and S wave automatic arrival time picking system which is accurate compatible with manual picking. This system selects several candidates of arrival times and selects one among them by using many kinds of threshold parameters based on the knowledge of earthquake expert. As a result, it is able to picks 2-3 times of accurate arrival times and determines 2-3 times of hypocenters compared to the catalogue by Japan Meteorological Agency. However, in the case of automatic system, it is difficult to completely eliminate wrong readings. It is required to conduct manual checking for the detailed studies such as the seismic tomography or focal mechanisms using polarity data etc. In this study, we present on a manual picking system which makes picking by correcting automatic readings.
2. Adjustment of picking parameters of automatic system
The automatic processing system can read data with low S/N ratio though accuracy is low. However there are cases in some researches that it is better to read only accurate data. Therefore, firstly, we changed threshold levels defined in the software of automatic picking so that the accuracy or the number of pickings fits to the research purpose. We change the threshold levels so that the number of picking by the automatic system become nearly same with it by the manually picking.
3. Manual arrival time picking system
The present manual picking system reads triggered waveform data and conducts the automatic picking based on the threshold levels mentioned above. Next, it displays waveform data together with picked arrivals for about 10 stations simultaneously. The manual picking is made by searching for erroneous readings of automatic pickings and correcting them. It is possible to select one among waveforms of 1) Raw, 2) High-pass filter, 3) Filter by the AR model in the P wave correction and 1) Raw, 2) High-pass filter, 3) SH component, 4) P and S wave discrimination filter, 5) absolute value of horizontally component in the S wave correction. We added a function to display waveform data of only stations with large arrival time residuals. We also added various functions so that the mouse operation becomes minimum at times of changing time scale and shifting time axis, etc.
4. Results
There is a data set of arrival times picked manually by an experienced seismologist which are used for the training of how to make manual pickings. Using this data set, we changed parameters of the threshold level of automatic picking so that the number of pickings becomes nearly same between the automatic and manually picking. There are 19 events in the data set. The numbers of P and S wave arrival times are 1124 and 936, respectively and 806 polarity data. These values by the automatic were 1193, 1300, and 747, respectively. We compared the difference between P and S wave arrival times picked automatic and arrival times in the data set. We found that more than 90 % of P wave arrival time differences are within 0.025 second, and 90% of S waves within 0.05 sec. The number of polarity read by the two was 663, and 99% of readings are consistent. This result shows that required corrections of automatic pickings is limited to a small number. Because of the introduction of accurate automatic picking software in the manual picking, a veteran operator can conduct manual picking within about 5 minutes for an event having P and S wave arrivals from about 100 stations.

Keywords: Manual arrival time pickimng, Automatic arrival time picking, Automatic polarity picking , Automatic picking compatible with manual picking

Improvement of P-wave detection algorithm using kurtosis statistics

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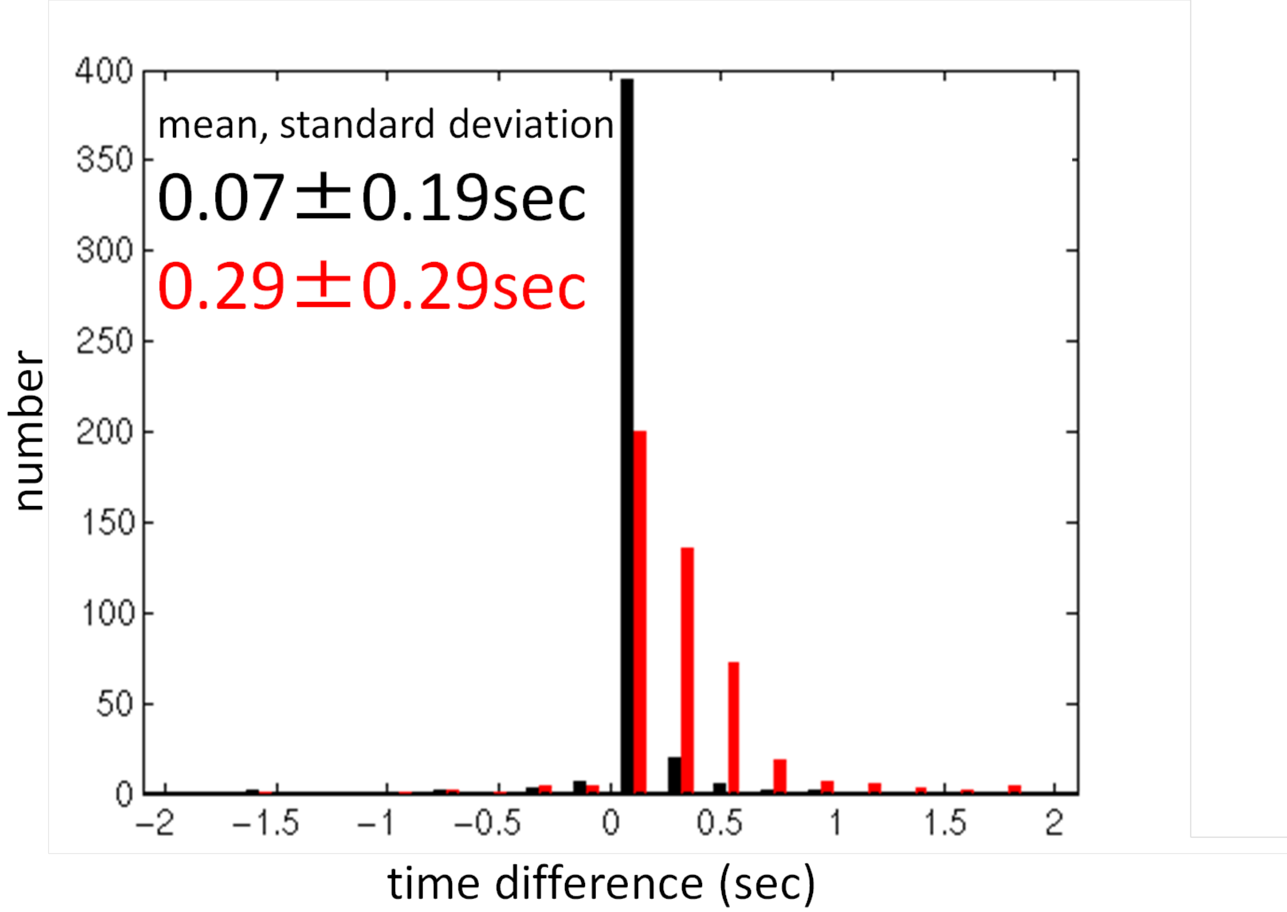
The current earthquake early warning (EEW) system in Japan uses the STA/LTA algorithm (Allen, 1978) to detect P-wave arrivals. Recently, Saragiotis et al (2002) proposed a method to identify the P-waves by using kurtosis statistics, which was more robust to a noise than the STA/LTA method. The method was used to create seismic catalogs, and designed for off-line process. To apply this method for the EEW system, we need a modification to make the calculation causal and enable the real-time processing and evaluate the performance of this method.
To test this kurtosis method, we use continuous waveform of the Hi-net and JMA strong motion records for 17 earthquakes between March 11, 2011 and April 16, 2011, which recorded the seismic intensity greater equal to 6 lower in the JMA intensity scale. An attached figure shows the time difference between the P-wave arrival time determined by this kurtosis method or the STA/LTA method and JMA manual picking time. The mean and standard deviation are 0.07±0.19 sec for this kurtosis method and 0.29±0.29 sec for the STA/LTA method, respectively. It shows that this kurtosis method tends to determine the P-wave arrival time more accurately than the STA/LTA method.
One of the disadvantages of this kurtosis method is that it is also sensitive to the pulse-like noise, so applying a noise filter is necessary to achieve the sufficient performance of the signal triggering.
The kurtosis method will contribute to improve the accuracy of source location determination of the EEW system and improve the shaking intensity estimation for EEW system.

Keywords: kurtosis, P-wave detection, earthquake early warning system


mean, standard deviation
0.07±0.19sec
0.29±0.29sec
number
time difference (sec)
400
350
300
250
200
150
100
50
0
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2

Earthquake Risk Management System Topology of Bursagaz Natural Gas Network, Bursa, Turkey

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Turkey is one of the most frequent earthquake occurred countries in the world. When we look at earthquakes occurred last fifteen year, over 18.000 people has lost their lifes .Especially the cities have high population and big industry areas are a part of 1 st degree earthquake zone. Bursa is one of these cities has a naturel gas network that is vulnerable against earthquakes which causes a grave risk for residential and industrial customers and people live in city.
The seismic safety of gas distribution has been the major project topic of distribution companies in past decades. In case of earthquakes the companies aim to secure their networks and minimize possible effects /potential risks of earthquake such as fire and explosion on the pipeline. Within this context Bursagaz Distribution Company created a pilot project in Bursa city of Turkey. Bursagaz is the one of private gas distribution Company which has Earthquake Risk Management Project in progress and also it is the second largest gas utility company which leads the innovated projects of gas sector in Turkey. After Bursagaz SCADA Project completed in 2012, network control system has been smarter and this was an opportunity to build earthquake Risk Management as well.
In Bursa city if any earthquake occurs, earthquake risk management system that set up Bursagaz network integrated with SCADA System, will evaluate acceleration data and generates earthquake acceleration data for scada. Scada decides what it is going to do with these acceleration data. When the Scada system is triggered with the data, the earthquake scada scenarios will be performed. The necessary valves and gas stations will be closed automatically and therefore gas supply will be stopped in some areas.
In addition when shortly after earthquake is over, exact emergency procedures and scenarios will be performed faster by emergency intervention system and actions will be taken by crews according to their roles. As a result of this, the network will continue safe gas supply with minimum losses and citizens safety will be ensured.

Keywords: Earthquake Risk Management System, Early warning and Rapid Response, SCADA

Study on Simple and Easy Estimation Technique of Evacuation Completion Ratio Considering Various Regional Characteristics

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1. Introduction

The ” Strategic Innovation Promotion Program (SIP)” of the Cabinet Office need to a method of predicting human casualty by using tsunami inundation data obtained from real-time observation data obtained immediately after the earthquake.

For prediction of human damage caused by the tsunami, it is important to accurately predict the number of people who can’ t arrive at the evacuation place until tsunami reaching. In order to accurately estimate the number of incomplete evacuation, it is necessary to consider various regional characteristics, and Takahashi et al. (2016) suggest distance to evacuation place as a regional characteristic relating to evacuation.

To predict the number of incomplete people, two method is used. One is tsunami evacuation simulation, and another is a method using evacuation completion rate curves of time until inundation reaching. Simulation can take various regional characteristics into consideration, but it is difficult to apply to immediate damage estimation over a wide range because it takes long time to calculate. While the latter is suitable for extensive damage estimation, there are problems from the viewpoint of reflection of regional characteristics.

Therefore, we tried to create a function to estimate evacuation with considering regional characteristics.

2. Parameterization of Evacuation Awareness

In the past method, evacuation awareness is defined in several stages such as "high / low". Meanwhile, the actual situation of the tsunami evacuation from the Tohoku earthquake varies widely depending on the region.

Therefore, based on the evacuation start ratio (= the number of people who started evacuation actions / the number of residents in the inundate area) for each elapsed time indicated survey of Tohoku earthquake, we try to show the evacuation start ratio by the cumulative distribution function of the lognormal distribution with the elapsed time from the occurrence of the earthquake as the explanatory variable. Furthermore, we made it possible to calculate the evacuation start rate only with parameter λ.

3. Evacuation Speed Estimation

Simulation was conducted to reproduce the evacuation from the Tohoku Tsunami first for the 7 areas. The simulation evacuation completion ratio was within the range of the evacuation completion ratio estimated from actual evacuation, and it was valid for the simulation. Next, we conducted a tsunami evacuation simulation that changed the evacuation awareness and examined the evacuation traveling speed by evacuation means / age / generation time (day / night).

We examined the evacuation speed of 7 areas and set the average evacuation ratio of evacuation measures and age from 3 categories (youthful walkers, elderly walkers, and using cars).

4. Creation of Prediction Formula for Number of People Unable to Evacuate

In order to complete evacuation, it is necessary to start evacuation until "limit time" which is the time of reaching the tsunami minus the time taking for evacuation. The number of people who start evacuation by this "limit time" can be predicted from the lognormal distribution with the evacuation awareness as the explanatory variable in the previous section. Specifically, the number of evacuees completed by multiplying the number of evacuees by age hierarchy / evacuation measures by the evacuation start rate within evacuation delay time is estimated.

5. Verification of Created Prediction Expression

In order to verify this prediction formula, we compared it with the result of the tsunami evacuation simulation. As a result, the error from the simulation result was about 50% or less. On the other hand, errors tended to increase in areas with a small inundated area.

Acknowledgment

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Keywords: tsunami, evacuation, simulation, regional characteristics, prediction formula

An approach for displaying real time data from seismic intensity meter maintained by a local government –Case study on Tottori prefecture -

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An approach for displaying real time data from seismic intensity meter maintained by a local government is demonstrated. Dense observation network is desirable for upgrading accuracy and quality of Earthquake Early Warning System. Seismic intensity meters installed all municipalities before recently conducted great synoecism are the most suitable equipment for the purpose. The seismic intensity meters in Tottori prefecture are improved to broadcast peak ground acceleration and seismic intensity every one second and a system displaying the data. In addition, observed data analyses and field surveys using microtremors are conducted to evaluate site response at the seismic intensity observation stations for more accurate seismic intensity estimations. The system is developing by loading results of the analyses and observations to estimate real time or prospective intensity distribution.

Keywords: Local Government, Seismic Intensity Meter, Real Time

A REVISION OF THE CUMULATIVE ABSOLUTE VELOCITY (CAV) THRESHOLD LEVEL VALUES FOR VRANCEA EARTHQUAKES

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Strong earthquakes in the Romanian Vrancea area have caused a high toll of casualties and extensive damage over the last several centuries. With a moment magnitude of 7.4, the last strong Vrancea earthquake on March 4, 1977 caused more than 1500 casualties, the majority of them in Bucharest. Strong earthquakes in the Vrancea zone occur between 60-200 km depth within an almost vertical column. Bucharest Earthquake Early Warning (EEW) system detects earthquakes with a seismic network in the epicentral Vrancea region and issue a warning in Bucharest providing 20-25s warning time.
To enhance EEW capability and to decrease the effects of Vrancea earthquakes on the populated cities for Romania, in particular on Bucharest city, the relationships of the bracketed cumulative absolute velocity window (BCAV-W) approach versus epicentral distance and magnitude for Vrancea region were investigated, in 2013, within the scope of the *Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation* (NERA) project. With in the context of this study the rational threshold levels related to M_w=5.4+ earthquakes were given as 0.28 m/s and 0.34 m/s.
To advance the actual EEW capability further, in this study, the number of previously used data has been increased with few earthquakes M5+ and a dataset of about 150 acceleration records which consists of intermediate depth earthquakes with different magnitudes ($4.0M_w6.0$) and with epicentral distances of less than 200 km has been used. BCAV-W approach versus epicentral distance and magnitude for Vrancea region have been reinvestigated.
In conclude, new rational threshold levels related to M_w=5.6+ earthquakes have been determined as 0.28 m/s, 0.36 m/s and 0.48 m/s related to 8-second, 12-second and 16-second windows, respectively.

Keywords: Earthquake Early Warning, Cumulative Absolute Velocity