A Note on Detection and Application of Small Seismic Events Preceding Major Earthquakes

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Abstract: *The earthquake early warning is a new technique to issue emergent information to take appropriate methods for disaster mitigation. We need rapid and accurate depiction of P-waves of major earthquakes. During the process to develop the method very small seismic events are often found to precede target large earthquakes. Majority of tested 40 major and moderate earthquakes (98%) were found to be preceded by those small seismic events in time period less than a minute before the main phase. Most of the events have less than 1s duration time and acceleration of some 1 gal. Those events are assumed to be induced in the stage before the nucleation stage of main phase. The events should be discarded in real time for the earthquake early warning but can be used to issue a prediction alarming for disastrous earthquakes several ten seconds earlier than by using the earthquake early warning.*

Keywords: Ultra-micro seismic events, precursory anomalies, seismic activities, earthquake early warning, earthquake prediction

1. INTRODUCTION

The earthquake early warning (EEW) are used in Japan generally for public alarming to help people to take emergent actions against the big earthquake shocks([1],[2],[3]). Present status of utilization is limited almost all to this purpose. But there are another important field to use the alarming. It is for an emergent shut down of important facilities just before arrival of major shock. For examples, there are several successful shut down at the major earthquakes in Japan to have saved the semiconductor factories from possible huge losses amounting order of billion US$ [4]. The application to the important facility situated near to the dangerous strike slip fault needs another level of accuracies and rapid calculation to have enough available time before arrival of S wave.

In order to achieve the goal, we tried to detect the P wave strength and estimate strength of S-wave strength using experimental ratio between P wave strength and S wave strength at the site ([4]). Especially there are not a small need for users situated near the fault where it is hard to get enough available time to guard the machine from the abrupt strong shock. There are two problems to attain this goal. One is fast and accurate detection of P-wave and another is to estimate major S wave in very short time, such as less than 0.5s because of necessary available time and possible time depending on hypocenter distance. In the course of this effort using the strong motion data of the National Research Institute for Earth Science and Disaster Resilience (NIED), it is found that there are very small earthquakes events. They are too small not to be included in the seismic catalog of highest sensitive seismic network in Japan, Hi-net of NIED. Those events are analyzed here from the point of utilization for EEW and earthquake prediction.

2. DATA AND ANALYSIS

Each data of the K-NET is taken by the event recording with the waiting time of 10~60 seconds in front of the P-wave arrival. These parts of data have been almost neglected in the strong motion seismology. We found that there occurred frequently very small seismic events preceding the target earthquake. Usual analysis need not take account of these events by disregarding smaller events. But we cannot look out even these minor events in the accurate picking of P-wave of similar strength of P-wave of moderate earthquake and the small events.

Fig. 1 shows UD component waveform of representative event. The sample earthquake in Fig.1 is a major earthquake(M6.3, Aril 15, 00:03:46.5) occurred in between the large pre-shock (M6.5) on April 14, 2016 and main shock of the Kumamoto earthquake (M7.3) on April 16,2016. The data are at the KMM006 station of the K-net. Fig1a shows whole waveform of

UD component of this earthquake. The long vertical red line shows the arrival time of true P wave, shorter red vertical lines show the small events of the present focus. In this case, the recording started 37seconds earlier before the P-arrival. This time period is the time period when the small events can be found in this work. Lengths of the waiting time ranges from 15s to 90s depending on triggering condition of each earthquake.

In Fig. 1a there are three small events at first and two events just before the P arrival. Fig 1b is to show waveform of small seismic events preceding the main phase of the earthquake with the vertical scale of 100 times compared with Fig 1a. The first event 1 is the largest with the maximum strength of 2gal. The event is checked not to be included in the official seismic catalog of Hi-net (NIED). It is because the event is too small to be detected at more than 4 sites separated 25km in average.

We used 40 earthquakes occurred very near to the evaluation points with epicentral distance of less than 15km. Total of 30 sample earthquakes are main shocks and aftershocks of the Kumamoto Earthquake in 2016. And another two earthquakes are the Tottori earthquake of magnitude 5.5 including 5 after-shocks and the south Ibaraki-ken earthquake of magnitude 5 including 5 aftershocks (Table 1). It is found that almost all moderate and major earthquakes with magnitude range (3.5-7.3) are accompanied with the small seismic events of the duration of about 1s (0.6~1.1) and acceleration strength of about 1 gal (0.7~1.9). All of the earthquakes are preceded by the small event except the Tottori earthquake. The mean strength ranges 0.05 to 1.9gal with standard deviation of 2gal in case of the Futagawa zone. Strengths at Futagawa are a few times larger than other places, and there are three earthquakes having strength of 2.6~6.6gal. Such “large” events of magnitude of about 2 were listed in the Hi-net micro-earthquake catalog.

There is significant correlation (maximum of 0.7) between the duration time and the strength of the small events. It is suggested that the events are thought to be seismic events, but are not noises. Magnitude of these ultra-micro events were found to range around -0.5based on the empirical formula between duration time and magnitude. Those small events are not included in the catalog of the Hi-net. Further analysis showed that the small events are composed of two groups, one is clearly separated with the main phase, and others connected to the main phase. Almost all the small events are separated from the main phase of earthquake.

3. DISCUSSION

Intensive experiment was conducted to investigate seismic and strain anomalies preceding the main shock of the major earthquake with M6.0 from the point of check if there are meaningful precursors[5]. They used accelerometer and dilatometers. It is concluded that there are almost no anomalies larger than 10^-9 strain and displacement larger than 10^-9nm for 25s at three stations and none anomalies for remaining six stations near the nucleation zone of the 28 September 2004, M 6.0 Park field earthquake during 2.3sec. This extremely small strength is suggested to be due to twice integration of the accelerometer data to get the displacement signal.

Focal parameters of more than 14,000 small earthquakes are determined [6]amid many after-shocks of the Kumamoto earthquakes. Hypocenters could not be determined because of waveforms are influenced by many aftershocks. They used the matched filter method[7] to discriminate those events by using original continuous Hi-Net data. They used template events of some 3,500 having 14 P-wave arrival times. It is suggested that the relocated events are much larger than the present small seismic events.

Seismic activity just preceding the P phase has been extensively studied ([8],[9]). They found there are slow initial phase preceding the P -phase as nucleation of main rupture. The phase just preceding the main phase obtained in our samples are assumed corresponding to these phenomena. The duration of the pulse is found to relate with the magnitude of the earthquake suggesting possibility to estimate strength of the shock at target point. And, [10] made interesting discussions on the starting phase of the main rupture by means of observation and numerical experiments. The events connected with the main phase induced in the nucleation process of main rupture. The disconnected small events found in this case, however, suggest that the nucleation phase is not restricted to the connected part, but started much earlier to be shown by more small resolving observation techniques. Those small events are thought to be another kind of phenomena appeared in the nucleation stage started much earlier than the so-called slow initial rupture phase. However, this part of the fluctuation should be discarded from the point of finding of accurate P-wave arrival.

Micro-cracks of typical frequency 400Hz are reported by means of seismo-electromagnetic observation [11]suggesting there are preliminary stage about a week before the main rupture. Time scale is same as pre-shocks[12]. We think the main events is

phenomena occurred in the stage. But events with different time scale suggests different adjusting process a little bit earlier than the slow initial phase.

Swift estimation of P phase enables us to estimate maximum acceleration of the earthquake in short time as 0.5 sec with enough accuracy to be applied to the emergent shut-down of the important machines. Similar approach was tried by [13]. They used seismic displacement data during 2s from the arrival of P-wave using the so called τ_c parameter deduced from average of f^2 weighted frequency (f) spectrum of displacement *u(t)*. This method uses the main phase of seismic wave to estimate S-wave for EEW.

The small seismic events can be used as precursory phenomena to the major earthquake though the available time is from a few seconds to 1 minute. This length of time seems almost negligible for general needs, but there are many machines and systems which can be controlled within 2s for emergent shut-down. The time is enough useful at this time of no practical useful prediction of damaging earthquake.

4. CONCLUSION

Almost all major earthquakes are found to be preceded by small seismic events which are not included in the official seismic catalogs of NIED. Almost all those events are disconnected with the main phase of the earthquakes. There are rare events connected with the main phase. The connected events are assumed to be slow initial phase or nucleation phase. The disconnected small events are assumed to be induced in the preparation stage of rupture, late stage of nucleation but earlier than slow initial phase preceding the P -phase as nucleation of main rupture. Those events should be picked and disregarded for EEW. But they can be used for imminent earthquake prediction before though less than a minute. Even a small time before the arrival of dominant seismic phase is useful and crucial from the point of shutdown of important factory. Further researches are needed to use the small events to apply to the prediction.

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REFERENCES

[1] S. Horiuchi, H.Negishi, K. Abe, A.Kamimura, and Yukio Fujinawa, *Bull. Seismological Society America*., **95**, 708-718, 2005, "An Automatic System for Broadcasting Earthquake Alarms"

[2] O.Kamigaichi(2004), earthquakeearly warming, J. JapanAssociation of EarthquakeEngineering,4,134-137.

[3] Y.Fujinawa and Y. Noda (2013) Japan's Earthquake Early Warning System on 11 March 2011: Performance, Shortcomings, and Changes Yukio ,Earthquake Spectra, Volume 29, No. S1, pages S341–S368,

[4] Y. Fujinawa, Y. Rokugo, Y. Noda, Y. Mizui, M. Kobayashi, E. Mizutani, Development of application systems for earthquake early warning"*J. Disaster Res.***4**(No.4), 2009.

[5] M.J.S.Johnston, R.D.Borcherdt, A.T.Linde, and M.T.Gladwin (2006). Continuous borehole strain and pore pressure in the near-field of the 28, September 2004, M 6.0 Parkfield, California, earthquake: implications for nucleation, fault response, earthquake prediction, and tremor, Bull. Seism. Soc. Am. 96, no. 4B, S56–S72.

[6] A.Kato1, J.Fukuda, S. Nakagawa, and K. Obara(2016) Foreshock migration preceding the 2016 Mw 7.0 Kumamoto earthquake, Japan, J. Res Letter,

[7] D.Shelly, G. Beroza, and S. Ide (2007), Non-volcanic tremor and low-frequency earthquake swarms, Nature, 446, 305–307, doi:10.1038/ nature05666.

[8] Y.Iio(1992), Slow initial phase of the P-wave velocity pulse generated by micro-earthquakes, Geophys.Res.Let., 19, 477-480, 1992.

[9] Y.Umeda, (1990),High-amplitude seismic wave radiated from the bright spot of an earthquake, Techtnophysics. 175,81-92

[10] B. Shibazakiand M .Matsu'ura (1998) Transition process from nucleation to high-speed rupture propagation: Scaling from stick-slip experiments to natural earthquakes, Geophys. J. Int. 132,14-30

[11] Y. Fujinawa, Y. Noda (2015), Characteristics of seismoelectric wave fields associated with natural microcracks, Pure Appl. Geophys. DOI 10.1007/s00024-015-1043-8.

[12] L.M. Jones, P. Molnar(1979), Some characteristics of foreshocks and their possible relationship to earthquake prediction and premonitory slip on faults, JGR,84,B7,3596-3608, doi.org/10.1029/JB084iB07p03596.

[13] Y. M Wu, and H. Kanamori (2005), Experimenton an onsite early warning method for the Taiwan early warning system, Bull. Seismol. Soc. Am. 95, 347–353, doi: 10.1785/0120040097.

Caption

Figure 1

a) UD component of a strong motion for whole waveform having small seismic events. Long vertical lines show arrival time of P-wave, red line is for the arrival time determined by real-time software and orange line is for the arrival time estimated by calculation. Short vertical lines are arrival times assumed for the small events.

b) The vertical scale is enlarged by 100 times for a)

c) The horizontal scale is enlarged by 25 times for b)

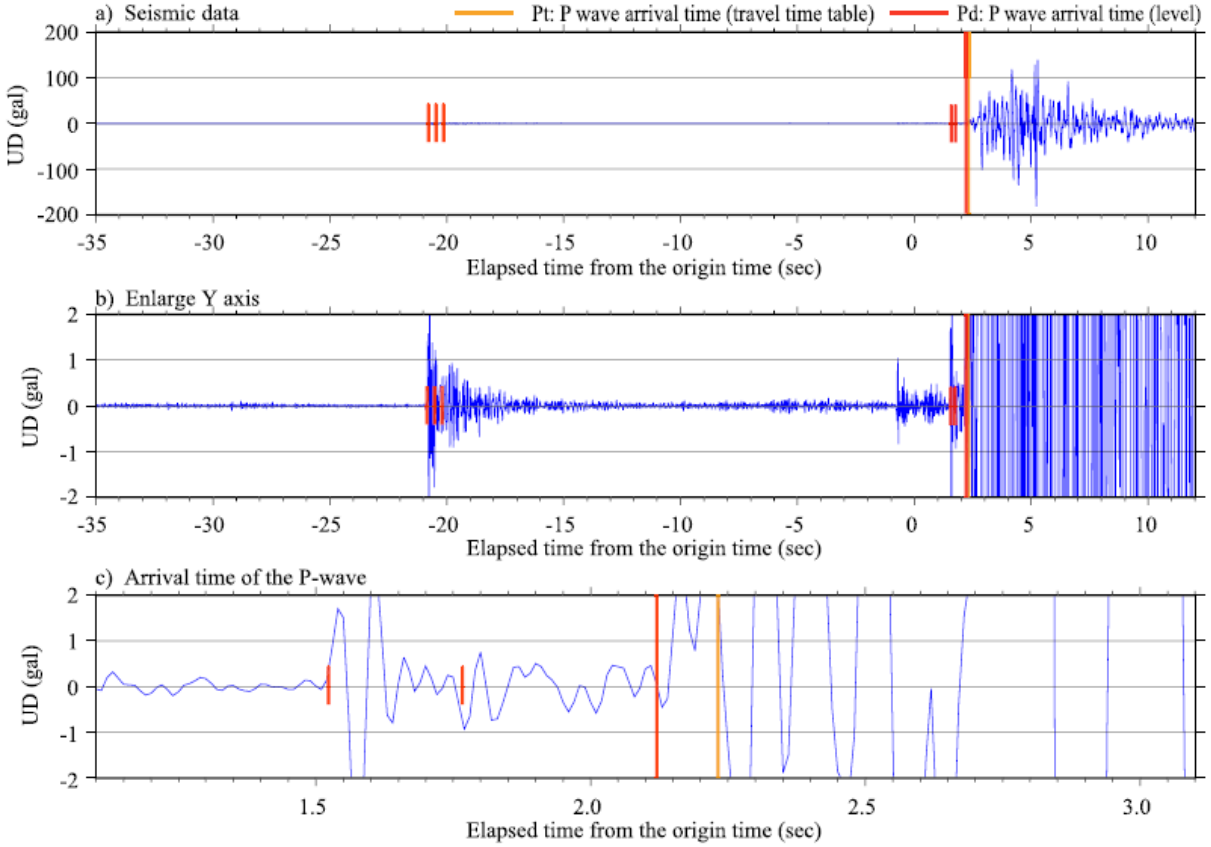

Table 1

Summary of the characteristics of small seismic events for three major earthquakes including 9 after shocks(three region of the Kumamoto Earthquake). Column for magnitude shows range of magnitude, ratio is number of earthquakes preceded by the small events/number of the earthquakes, duration is average duration time and standard deviation, strength shows mean and standard deviation, and "Corr." means the correlation between duration and strength of each events.

Earthquake	Number Eq.	Magnitude	Rate of appearance	Duration (s)	Strength (gal)	Corr. (duration/ strength)
Kumamoto (central)	10	4.6-7.3	10/10	0.8±0.3	0.7±0.1	0.32
Kumamoto (NE,Futagwa)	10	3.5-5.9	10/10	1.0±0.8	1.9 ±1.7	0.72
Kumamoto (SW:Hinaku)	10	4.4-5.0	10/10	0.7±0.2	0.3±1.0	0.42
Tottori	5	3.9-5.5	4/5	0.6±0.2	0.11±0.05	0.68
Ibarakigi-ken South	5	5.2-5.4	5/5	0.6±0.1	0.05±0.04	0.46