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Discrimination of DPRK February 12th, 2013 Earthquake as Nuclear Test Using Analysis of Magnitude, Rupture Duration and Ratio of Seismic Energy and Moment

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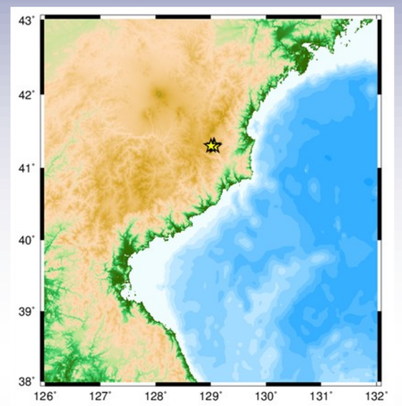
INTRODUCTION

On February 12, 2013 morning at 02:57 UTC, there had been an earthquake with its epicenter in the region of North Korea precisely around Sungjibaegam Mountains. Monitoring stations of the Preparatory Commission for the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO) and some other seismic network detected this shallow seismic event. Analyzing seismograms recorded after this event can discriminate between a natural earthquake and an explosion.



Underground nuclear explosions of kt up to Mt of equivalent TNT may be seismically recorded even world-wide (1 kt TNT = 4.2 x 10^{12} J) (Bormann, 2002). The explosion of a nuclear test can be detected and distinguished from natural events such as tectonic or volcanic earthquakes. This shallow seismic event on February, 12, 2013 considered as the third nuclear test by North Korea. Researching the characteristics of the seismic event can distinguish an explosion from natural earthquake. This is where the important of seismology as the study of seismic waves can be used to support the CTBT. Several studies have discriminate the nuclear explosion detonated by North Korea from natural earthquake such us Zhao *et al.* (2014), Murphy *et al.* (2013), Carluccio *et al.* (2012), Murphy *et al.* (2010), and Zhao *et al.* (2008).

Figure in the right shows us that North Korea mainland is not a shallow active tectonic area. So we should be suspicious of seismic events in the territory of North Korea as an underground nuclear test. The seismicity data shown in this research explained that the mainland region of North Korea is absence of sources of very shallow tectonic earthquake.

We proposed some method to discriminate the shallow seismic event in North Korea mainland in 2013 from natural earthquakes. Pribadi *et al.* (2013) have characterized 27 earthquake-generated tsunamis (tsunamigenic earthquake or tsunami earthquake) from 1991 to 2012 in Indonesia using W-phase inversion analysis, the ratio between the seismic energy (E) and the seismic moment (Mo), the moment magnitude (Mw), the rupture duration (To) and the distance of the hypocenter to the trench. Some of this method was also used by us to characterize the nuclear test earthquake. We discriminate this shallow seismic event on February 12th, 2013 as a nuclear test using analysis of the ratio between body-wave to surface-wave magnitude (mb:Ms), ratio of seismic energy and moment (Θ) and analysis of rupture duration (Tdur).

METHODS

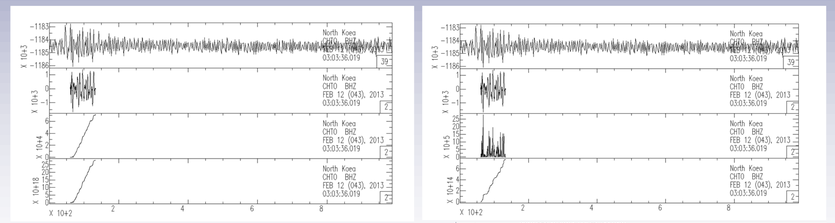
Ratio of mb and Ms

We calculate the mb and Ms of the DPRK February 12th, 2013 earthquake to investigate the mb-Ms plotting of this event on the mb:Ms event screening revisited by Selby *et al.* (2012). We manually calculate the body wave magnitude (mb) and surface wave magnitude (Ms) by using the IASPEI (International Association of Seismology and Physics of the Earth's Interior) standard measure (Bormann, *et al.* 2002).

Ratio of radiated seismic energy and moment

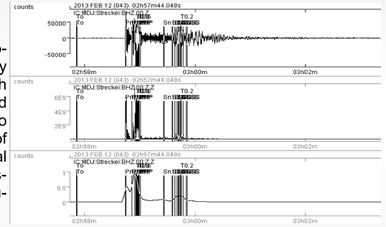
[Left Picture] The procedure of seismic moment calculation of the DPRK February 12th, 2013 earthquake. The seismogram manipulation from top to bottom: 1) ground velocity seismogram of CHTO station (nm.s^{-1}), 2) removing instrument response, cutting and filtering, 3) integrate to displacement seismogram, and 4) seismic moment (N.m)

[Right Picture] The procedure of radiated seismic energy estimation of the DPRK February 12th, 2013 earthquake. The seismogram manipulation from top to bottom: 1) ground velocity seismogram of CHTO station (nm.s^{-1}), 2) removing instrument response, cutting and filtering, 3) squaring, and 4) radiated seismic energy (N.m)



Rupture Duration Calculation

We calculate the rupture duration using the formula from Lomax (2009). We used the vertical-component ground velocity seismogram as the raw input data. We applied the Butterworth band pass filter in range 1-5 Hz and 4-pole. Then we converted the seismogram to velocity-squared envelopes smoothing to get the RMS amplitude. Next, we measured the delay time of 90% ($T^{0.9}$), 80% ($T^{0.8}$), 50% ($T^{0.5}$) and 20% ($T^{0.2}$) from the arrival time of P-wave which picked automatically by using Seisgram2K program. Then, the rupture duration (Tdur) was calculated.



DATA & RESOURCES

Waveform data of the three North Korea nuclear tests which analyzed in this study was downloaded from IRIS (http://ds.iris.edu/wilber3/find_event). We also used the table S1 in electronic supplement of Selby *et al.* (2012) study (http://www.seismosoc.org/publications/BSSA_html/bssa_102-1/2010349-esupp/TableS1.html). This was the data of the 409 past underground nuclear explosions collated and presented by Selby *et al.* (2012). The important data was also the table 2 of signal analysis result in study of Pribadi *et al.* (2013). This is the data of the result of seismogram processing by Pribadi *et al.* (2013) such us the estimation of seismic moment, radiated seismic energy and the rupture duration of the 27 earthquake generated tsunamis in Indonesia region. We also used the seismicity data in North Korean region downloaded from Reviewed Event Bulletin (REB) ISC (International Seismological Center) (http://www.isc.ac.uk/iscbulletin/search/bulletin/).

RESULTS AND ANALYSIS

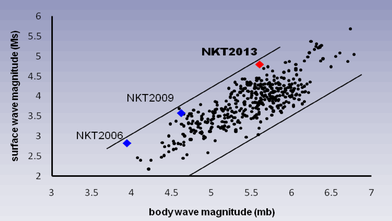
Table of the calculation result of all methods by this study:

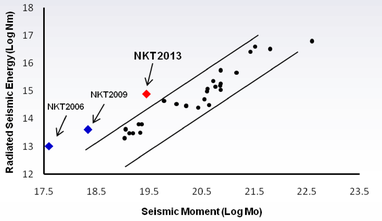
Event	P-PP (s)	Distance (km)	Mo (10^{17} Nm)	E (10^{13} Nm)	Θ	Tdur (s)
2006/10/09	13	3792.200	3.950354	1.036422	-4.58	12.82
2009/05/25	13	3792.245	22.03960	4.026303	-4.73	11.82
2013/02/12	14	3787.875	281.7822	76.52314	-4.56	11.13

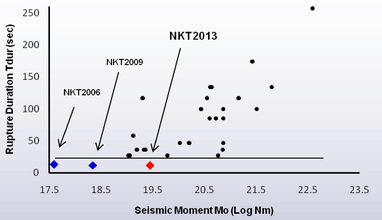
⇒From the results of the mb:Ms calculation we can concluded that the February, 12th 2013 earthquake in North Korea mainland was also an underground nuclear test. The result shows us that the three earthquakes in North Korea (NKT2006, NKT2009 and NKT2013 was classified as the explosion event proposed by Selby *et al.* (2012) based on the screening line. Selby *et al.* (2012) analyzed mb and Ms magnitudes for 409 past underground nuclear explosions and proposed the revised mb:Ms screening line based on these magnitudes is Ms=mb−0.64.

⇒The NKT 2013 has 2.817822 x 10^{19} N.m of the seismic moment and 7.652314 x 10^{14} N.m of radiated seismic energy. If we look for the result of the Pribadi *et al.* (2013) study, for the natural (tectonic) earthquakes, the seismic moment to be 1.07 x 10^{19} N.m ≤ Mo ≤ 3.89 x 10^{22} N.m and the radiated seismic energy to be 2.0 x 10^{13} N.m ≤ E ≤ 6.309 x 10^{16} N.m. But if we look for the Θ value, the three events did not have a large difference. The Θ for the three events were -4.58, -4.73 and -4.56 for the 2006, 2009 and 2013 event respectively. The equivalent Θ value of this three events show us the similarity of the sources. The seismic moment of the three shallow seismic events was closer to its value of radiated seismic energy than some natural earthquakes proposed by Pribadi *et al.* (2013).

⇒The three shallow seismic events in mainland of North Korea in 2006, 2009 and 2013 had a very low value of rupture duration (Tdur). The equivalent rupture duration values of these three events also show us the similarity of the sources. The very low value of the rupture duration from the three event above was considered as an implication of the unusual sources. The natural earthquakes analyzed by Pribadi *et al.* (2013) had the lowest 27 s rupture duration value. This was why we argue that the DPRK February 12th, 2013 earthquake can be also considered as an underground nuclear test. Compared to tectonic earthquakes, the duration of the source process of explosions and the rise time to the maximum level of displacement is much shorter (milliseconds as compared to seconds up to a few minutes) and more impulsive (Bormann et al., 2002).







CONCLUSION

We discriminated this DPRK February 12th, 2013 earthquake from a natural earthquake by using analysis of ratio mb:Ms, ratio of seismic energy and moment (Θ) and rupture duration. We used the waveform data of the shallow seismic event which occurred in the region of North Korea mainland in 2006, 2009 and 2013. We conclude that this earthquake was a shallow seismic event with explosion characteristics and can be discriminated from a natural or tectonic earthquake. The calculation result of mb and Ms of the DPRK February 12th, 2013 was made us classified this earthquake as the explosion event proposed by Selby *et al.* (2012) based on the screening line. The DPRK February 12th, 2013 earthquake had 2.817822 x 10^{19} N.m of the seismic moment and 7.652314 x 10^{14} N.m of radiated seismic energy and -4.56 of the Θ value. The equivalent Θ value of the three events shows us the similarity of the non-natural sources. The rupture duration value of this event was 11.13 s. The very low value of the rupture duration from the three event above was considered as an implication of the non-natural sources.