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SOURCE CHARACTERIZATION OF THE MID-SCALE CRUSTAL EARTHQUAKE USING THE EMPIRICAL GREEN'S FUNCTION METHOD

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Abstract

Characteristic strong ground motion which has large long period pulse with a duration of 1 to 2 second was generated in 1995 Kobe earthquake. It caused serious damage to many civil structures and many buildings. The characteristic ground motion was generated by forward rupture directivity effect and site amplification effect. After this earthquake, study on source modeling and strong ground motion prediction method were developed by many researchers energetically. As a result, "Recipe for strong ground motion prediction" was constructing based on several research findings. Effectiveness of the recipe was verifying by strong ground motion simulation against a large-size earthquake. Recently, structure or lifeline system damages caused by the mid-scale earthquake were reported. Generally, damage scale by mid-scale earthquake was not so serious, but that earthquake is often generated. So, it is important that study of the source modeling for the mid-scale earthquake. In this study, we attempted to make a source model of mid-scale earthquake. The earthquake of Mw5.2 which occurred in southern Nagano prefecture in Japan on 25th June 2017 was selected for target earthquake. Strong ground motions were generated near source area and caused severe damage to many wooden houses of standard type in Japan. We constructed a source model by the forward modeling using empirical Green's function method. Effectiveness of this procedure was verified by an application to other large-scale earthquakes. The source parameters of strong motion generation area were determined from the comparisons of the synthesized broad-band ground motions with the observed ones at several seismic stations in near source area. Resultantly, we proposed source model with single strong motion generation areas located in near hypocenter of main-shock. An acceleration source spectral level of this earthquake was satisfied to scaling law for large size earthquake.

Keywords: ground motion prediction, characterized source model, empirical Green's function method

1. Introduction

We know that large-scale earthquake caused serious damage to many civil structures and buildings. 1995 Kobe earthquake is one of the large-scale earthquakes. That earthquake created characteristic ground motion which include semi-large pulse with a duration of 1 to 3 second in near source area. It was thought that most of earthquake damages were generated by these characteristic ground motions. The characteristic ground motion was generated by forward rupture directivity effect and site amplification effect. After this earthquake, research on strong ground motion prediction including source modeling was conducted by many researchers energetically. As a result, “Recipe for strong ground motion prediction” was constructing based on several research findings. Effectiveness of the source modeling method was verifying by strong ground motion simulation against a large-size earthquake. Recently, structure or lifeline system damages caused by the mid-scale earthquake were reported. Generally, damage scale by mid-scale earthquake was not so serious, but that earthquake will be often generated. So, it is important to study source modeling of mid-scale earthquake. In this study, we attempted to make a source model of mid-scale earthquake by the forward modeling [1] using empirical Green's function method [2]. The target earthquake is inland crustal earthquake with Mw5.2 which occurred in southern Nagano prefecture in Japan on 25th June 2017. Resultantly, we proposed source model with single strong motion generation areas located in near hypocenter.

2. 2017 Southern Nagano prefecture earthquake

The earthquake of Mw5.2 which occurred in southern Nagano prefecture in Japan on 25th June 2017 was selected for target earthquake as mid-scale earthquake. The fault plane of this earthquake was estimated a reverse fault type with the strike of NNE–SSW direction from CMT solution [3] and after-shocks distribution. Fig. 1 shows location of the epicenter of the main-shock and after-shocks. These after-shocks were occurred within 24 hours from main-shock. Table 1. shows parameter of the southern Nagano prefecture earthquake [3], [4].

Strong ground motions were generated near source area in this earthquake and suffered to many wooden houses. Fire and Disaster Management Agency, Ministry of Internal Affairs and Communications was reported that 27 wooden houses suffered partial damage and many roads was closed by landslide and rock fall. A large-scale earthquake of M6.8 was generated at the near epicenter in 1984 and it caused heavy damages in near source area. The epicenter and CMT solution of this earthquake were shown in Fig. 1. Epicenter of two earthquakes were very closed but fault mechanism is different.

Table 1 – Source parameter of the 2017 southern Nagano prefecture earthquake

Origin time (JST)*	2017-6-25 7:02:15.3
Epicenter*	35°52.0' N 137°35.1' E
Depth (km)*	7
Magnitude**	Mw5.2
Seismic moment**	6.89×10^{16} Nm
STR/DIP/RAK**	219;13/ 40;53 / 111;73

* JMA[4], ** F-net[3]

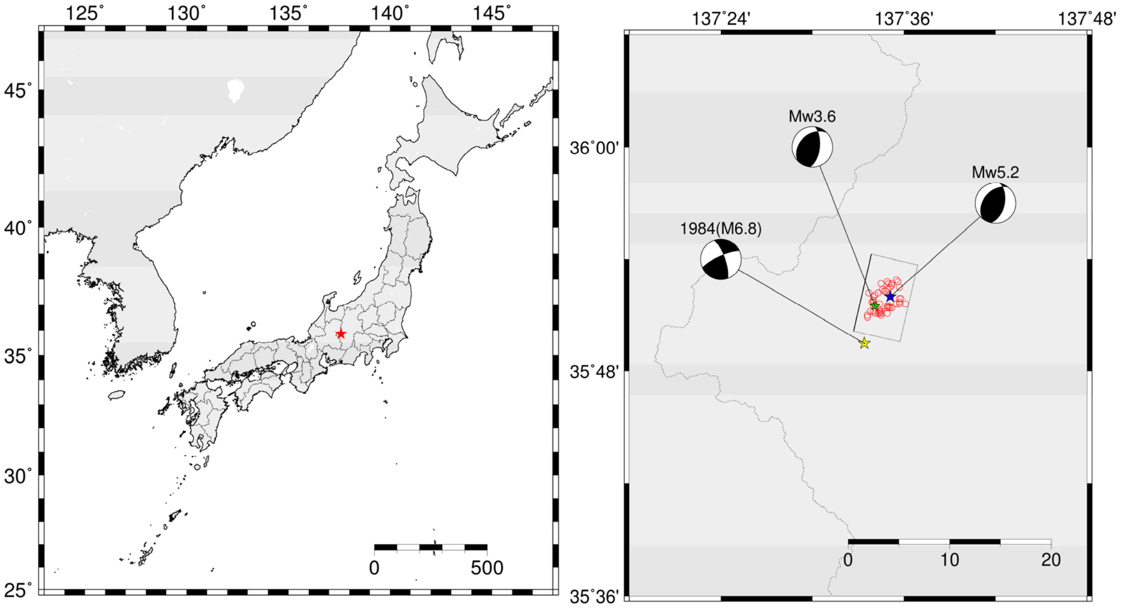

Fig. 1 – Epicenter of 2017 southern Nagano prefecture earthquake (Mw5.2) and after-shocks distribution which occurred within 24 hours. M6.8 earthquake occurred in 1984. Mw3.6 is the earthquake as used for empirical Green's function event.

3. Strong ground motions which observed in near source area

Ground motions in the wide area including near source area were observed at K-NET, KiK-net and local government seismic observation network. K-NET and KiK-net are seismic observation network of NIED [5]. Fig. 2 shows epicenter of main-shock and seismic stations. Red triangle mark indicate KiK-net, green triangle mark means K-NET and blue triangle mark is local government station.

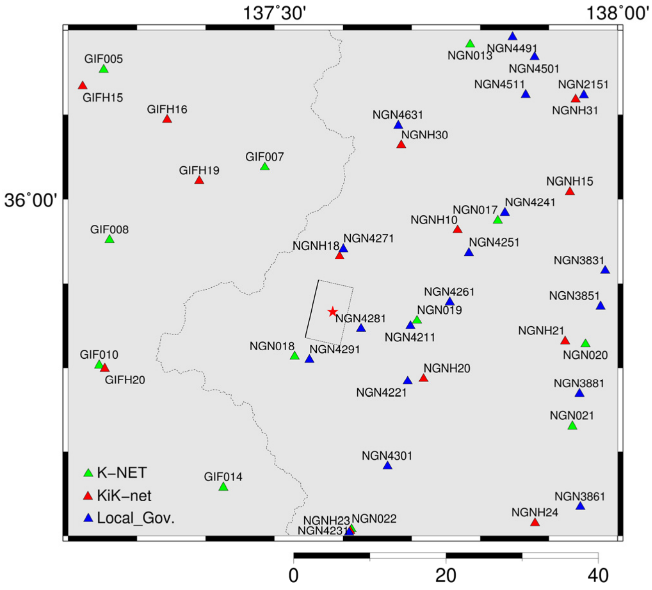

Fig. 2 – Location of the epicenter of the 2017 southern Nagano prefecture earthquake and seismic observation stations.

Fig. 3 shows acceleration waveform and velocity waveform which were observed at NGNH18 and NGN4281. Both records were observed on the ground surface. Velocity waveform was calculated from 0.1-10Hz band-pass acceleration waveform by Fourier integration procedure. NGNH18 was located in the strike direction of the fault plane. NGN4281 was located in the transverse direction of the fault plane. Duration of principal motion at each waveform were not so long. NGN4281 of the nearest station is about 2 seconds. Pulse wave was included in waveform at NGNH18, NGN4281 and NGN0181.

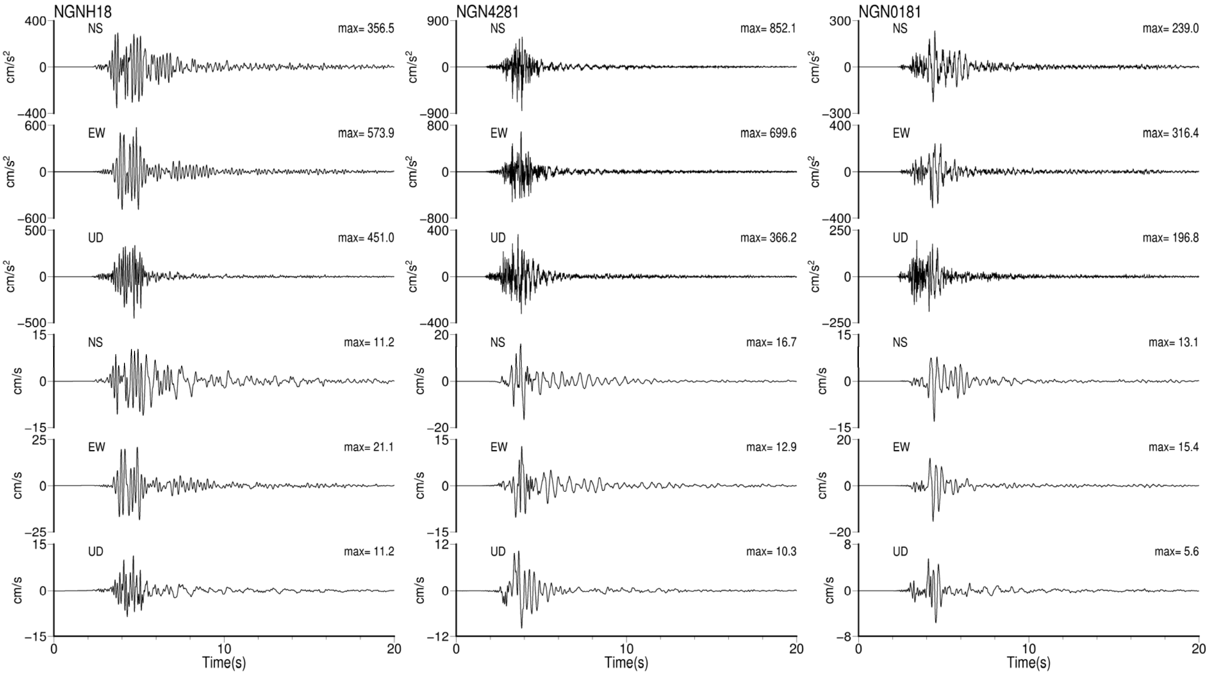

Fig. 3 – Acceleration and velocity waveform at NGNH18, NGN4281 and NGN0181.

4. Source modeling

4.1 Method

We attempted evaluating the source model of 2017 Nagano prefecture earthquake by forward modeling [1] using empirical Green's function method [2]. In this method, firstly we make an initial source model which consist of single or multiple strong ground motion generation area (SMGA). Location and number of SMGA are referred from waveform inversion result. Secondary, parameters of SMGA such as location, size, stress drop and rise time were tuned based on agreement between synthesis ground motion and observed one. The source model made by this procedure is called SMGA model.

Effectiveness of SMGA model was verified by previous researches [5] even though SMGA has a rectangular shape and homogenized physical property. In this study, we do not consider backward of source area because the strong ground motion was comprised of only elastic wave generated from SMGA. NGNH18, NGNH20, GIFH24, GIFH19, GIFH20 and NGNH30 were used as target site that compared synthesis ground motion with observed one. Because to remove the influence of the soil characteristics nonlinearity, we used under-ground records of KiK-net. Fig. 2 shows location of 6 stations.

4.2 Fault plane

A fault plane that includes the JMA hypocenter with a length of 7.8 km and width of 7.8 km was assumed by after-shock distribution. The strike and dip angles were set to 13 degree and 54 degree by referring to the F-net moment tensor solution. Latitude and longitude of reference point of fault plain were 35.836N and 137.545E. Fig. 2 shows fault plain.

4.3 Element earthquake as use for empirical Green's function event

The empirical Green's function method (EGFM) synthesize strong ground motion of large earthquake using similarity law between large earthquake and small earthquake. So, we have to very carefully select an element earthquake as use for empirical Green's function event. In this study, we selected element earthquake from 14 earthquakes which satisfied following condition.

1. Epicenter: 35.8N - 35.9N, 137.5E - 137.65E
2. Magnitude: $M_{JMA}3.5 – M_{JMA}4.5$
3. Focal mechanism of F-net: Evaluated

As a result, earthquake with $M_{JMA}3.5$ were selected as an empirical Green's function event. M_{JMA} means magnitude scale of Japan Meteorological Agency. Fig. 1 shows epicenter of element earthquake and focal mechanism by F-net. Table 2 shows source parameter of element earthquake. Area and stress drop were evaluated by Brune method [6], [7] and circular crack method [8]. Equation (1) and equation (2) shows Brune method and circular crack method. Corner frequency of element earthquake (f_{ca}) as use for Brune method was evaluated by source spectral ratio fitting method (SSRF method) proposed by Miyake et al. (1999) [9]. SSRF method fit a source spectral function based on ω^{-2} source spectral theory into an observed source spectral ratio and calculate f_{ca}, N and C. Here, N is number of synthesis and C is ratio of stress drop between large earthquake and element earthquake. Equation (3) shows source spectral function (SSRF(f))

$$r_e = \frac{2.34\beta}{2\pi f_{ca}} \tag{1}$$

$$\Delta\sigma_e = \frac{7}{16}\frac{m_0}{r_e^3} \tag{2}$$

$$SSRF(f) = \frac{M_0}{m_0}\frac{1+\left(\dfrac{f}{f_{ca}}\right)^2}{1+\left(\dfrac{f}{f_{cm}}\right)^2} \tag{3}$$

Here, f is frequency, r_e is equivalent radius (km), β is shear wave velocity of rock basement (km/s), $\Delta\sigma_e$ is stress drop of element earthquake (MPa), M_0 and m_0 are seismic moment of large earthquake and element earthquake respectively (Nm). f_{cm} and f_{ca} are corner frequency of large earthquake and element earthquake respectively.

In this study, we use main-shock to use as large earthquake. Observed source function ratio was calculated by broadband velocity records which observed at KNM, NAA, FUJI, TTO and SRN. Fig. 4 shows location of broadband seismic observation stations of F-net. Fig. 5 shows result of curve fitting. Range of curve fitting is 0.1 – 10 Hz. Read curve is SSRF and blue circle are target. We evaluated corner frequency (f_{ca}) to be 2.37Hz from curve fitting.

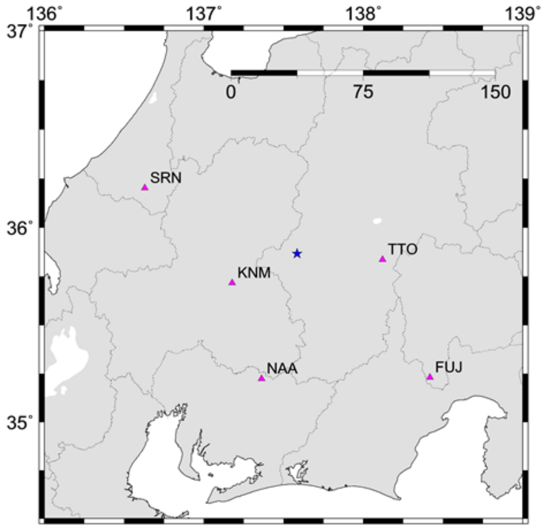

Fig. 4 – Location of broadband seismic observation stations of F-net.

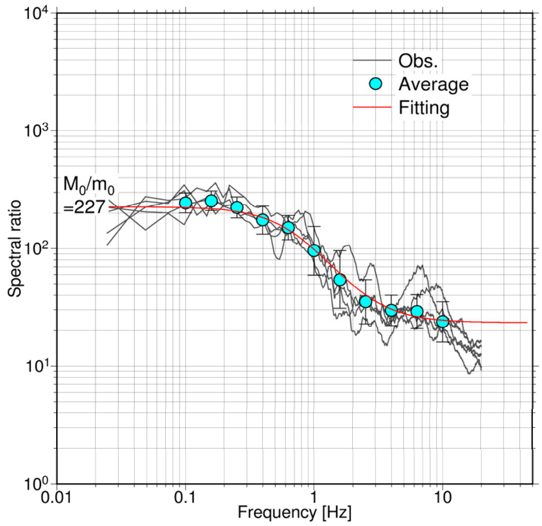

Fig. 5 – Curve fitting result between observed source spectral ratio and source spectral function.

Table 2 – Source parameter of the element earthquake to use as empirical Green's function event

Origin time (JST)*	2017-6-25 9:48:42.7
Epicenter[a]	35°51.5' N 137°34.1' E
Depth (km)*	6
Magnitude	Mw3.6
Seismic moment**	3.04×10^{14} Nm
STR/DIP/RAK**	227;7/ 37;60 / 124;67
Corner frequency	2.37Hz
Stress drop	0.8MPa
Area	0.95km^2

* JMA[4], ** F-net[3]

4.4 Source modeling

We set single SMGA because observation waveform does not see multi event. As a result of forward modeling, we make a source model with single SMGA which located in near hypocenter. Shape of SMGA is 2.925 km square. Fig. 6 shows source model of the 2017 Nagano prefecture earthquake. Table 3 shows parameters of the source model.

Fig. 7 shows the synthesized acceleration waveforms, velocity waveforms and displacement waveform at each target stations superimposed on the observation records. Fig. 8 shows the pseudo velocity response spectrum with damping factor 0.05 (response spectrum) and acceleration Fourier spectrum (Fourier spectrum). Effective frequency range is 0.2-10.0Hz. Synthesized acceleration waveform and velocity waveform at all stations were good agreement with observed ones. Especially, synthetic waveform can reproduce pulse waveform. Also, response spectrum and Fourier spectrum were good agreement with observed ones. Synthesized response spectrum and Fourier spectrum at GIFH24 is underestimated in more than 1Hz range.

Fig. 9 shows relationship between seismic moment and short period source spectrum. Equation (4) shows scaling law between seismic moment and short period source spectrum by Dan et al. (2001) [10]. Short period source spectrum of this earthquake was calculated by equation (4) [10].

$$A = 2.46\times10^{10}\times\left(M_0\times10^7\right)^{1/3} \tag{4}$$

$$A = 4\pi r\Delta\sigma_a\beta^2 \tag{5}$$

Here, A is short period source spectrum (Nm/s^2), r is radius of SMGA (km) and $\Delta\sigma_a$ is stress drop of SMGA (MPa). Shear wave velocity assumed 3.5km/s. Relation between seismic moment and short period source spectrum of this earthquake can be express by scaling law.

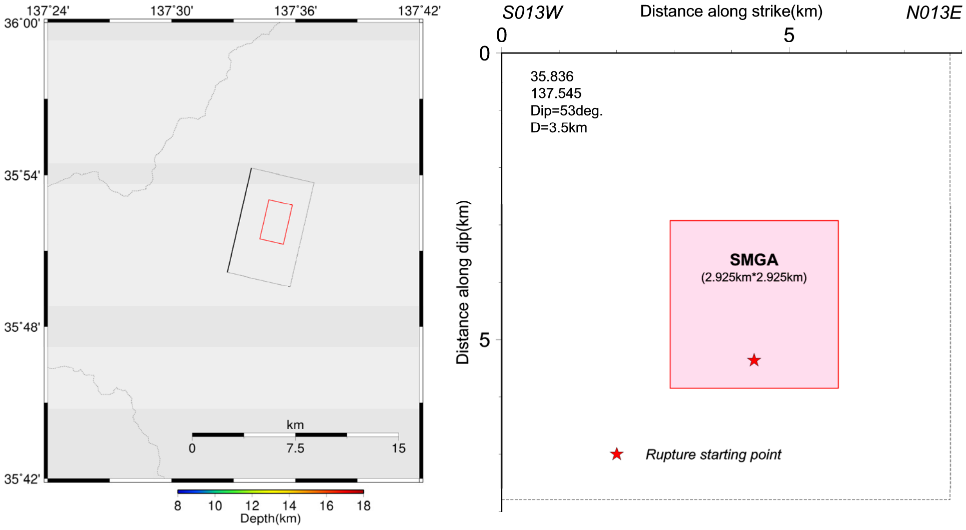

Fig. 6 – The source model of the 2017 Nagano prefecture earthquake.

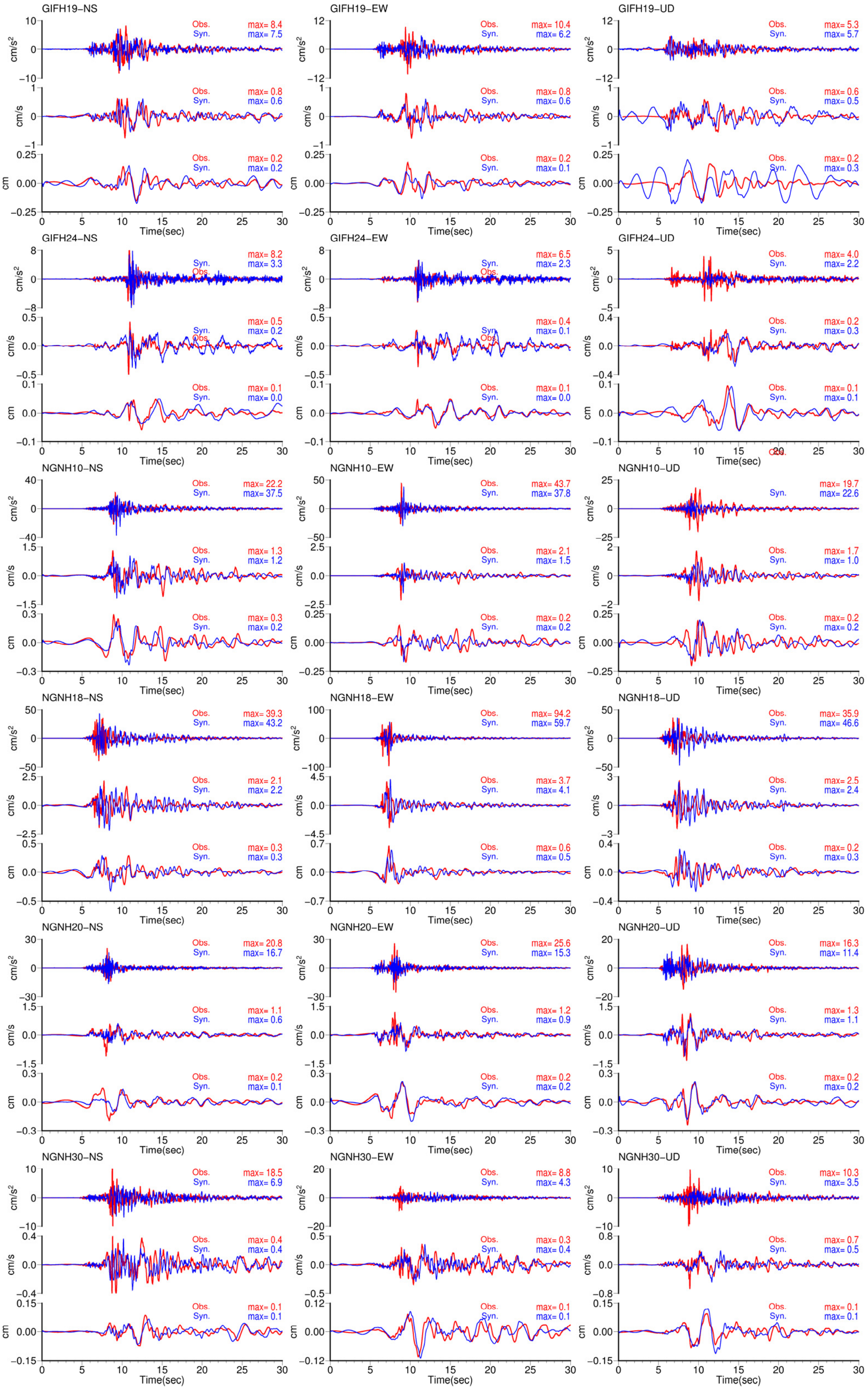

Fig. 7 – Comparison of the observed and synthetic waveforms of EW component at target station. The red color lines are the observed waveforms.

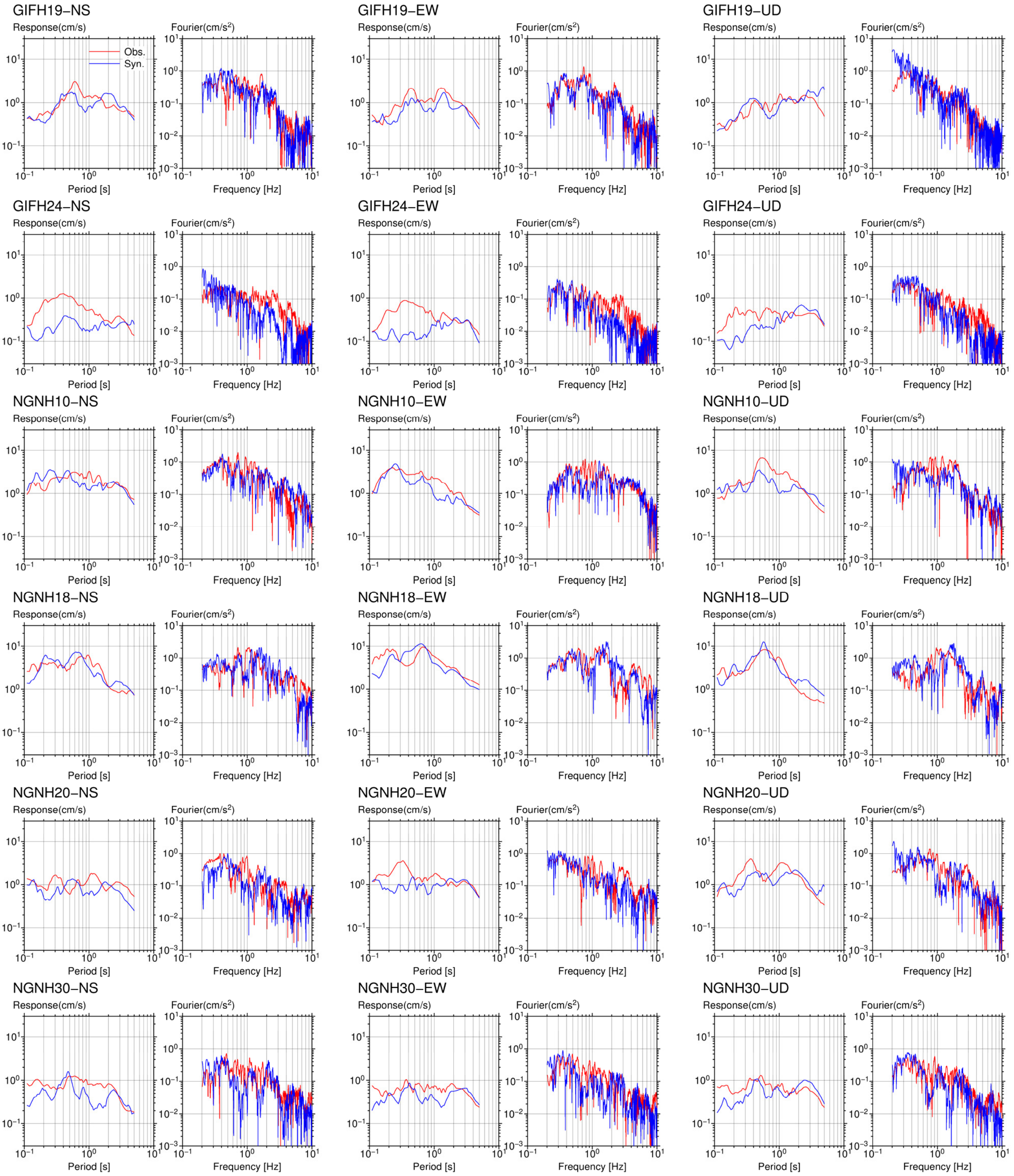

Fig. 8 – Comparison of the observed and synthetic pseudo velocity response spectrum and acceleration Fourier spectrum at target stations.

Table 3 – Parameter of the source model

Area	8.56km^2 (2.925km×2.925km)
Synthesis number	3×3×3
depth (upper)	2.925km
Stress drop	6.4MPa
Rupture velocity	2.7km/s
Rise time	0.2s

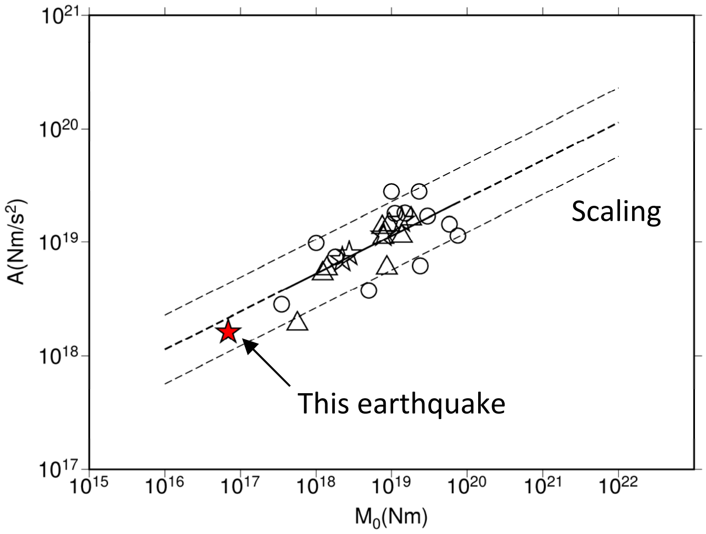

Fig. 9 – Relation between seismic moment and short period source spectrum.

5 Conclusion

We constructed the source model of 2017 Nagano prefecture earthquake with Mw5.2 by the forward modeling using empirical Green's function method. The source model has a single SMGA. Relation between seismic moment and short period source spectrum can be express by scaling law.

6. Acknowledgements

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