Journal of Earth Sciences 2 (2016) 11-18
ISSN 2372-5176

Betty Jones & Sisters Publishing
http://www.bettyjonespub.com

Estimation of Empirical Green's Tensor Spatial Derivative Elements: A Preliminary Study Using Strong Ground Motion Records in Southern Fukui Prefecture, Japan

Michihiro Ohori

Research Institute of Nuclear Engineering, Universtiy of Fukui, 1-2-4 Kanawa-cho, Tsuruga, Fukui, 914-0055, Japan

Abstract: To demonstrate the applicability of the empirical Green's tensor spatial derivative (EGTD) method for simulation of near-field strong ground motion records, we simulated velocity waveforms between 0.25 and 1 Hz. We used data from seven events (M_J 3.7-4.2) in the southern part of Fukui Prefecture, Japan observed at FKI007, one of the K-NET stations operated by the National Research Institute for Earth Science and Disaster Prevention (NIED). Agreement between the observed and calculated waveforms for all events was satisfactory over a long duration and there was a good match for the amplitude. To enhance the applicability of the EGTD method, further data accumulation and investigation is recommended.

Key words: Empirical Green's tensor spatial derivative (EGTD), focal mechanisms, waveform inversion, strong ground motion, moment tensor

1. Introduction

The empirical Green's tensor spatial derivative (EGTD) method, proposed by Plicka and Zahradnik [1], has the potential to deal with differences in focal mechanisms between a targeted event and other small events, and to predict the ground motion for an event with an arbitrary focal mechanism. The EGTD elements are estimated through a form of single-station inversion using waveform data from several small events whose focal mechanisms and source time functions have been well determined. Although this technique is expected to provide results of considerable accuracy and prediction stability, discussion of its application has been limited in the literature [2-7]. Further data accumulation and investigation will enhance the applicability of the EGTD method.

I estimated the EGTD using seven small events (M_J 3.7-4.2) in the southern part of Fukui Prefecture, Japan. Fukui Prefecture is an area with relatively low seismicity compared with other parts of Japan and strong motion data for EGTD estimation is less abundant. Most of the events used in this study occurred within or near the Mikata Fault Zone, where earthquakes of magnitude 7.2 are expected with a recurrence period of 3,800-6,300 years [8]. There are nuclear power stations of various types along the coastal area close to the fault. This preliminary study in such an area is significant in its evaluation of the value of strong motion prediction using EGTD, which demonstrates the potential for greater use of EGTD estimation.

2. Method

The estimation method of EGTD has been explained fully by Ohori and Hisada [4-5]. It is applicable to simulation of strong motion in a frequency range below the corner frequency. I briefly summarize the method below. Ground motion displacement $u_i(x_o, t)$ $(i = x, y, z)$, excited by a double-couple point source, is theoretically expressed as the convolution of moment

---

Corresponding author: Michihiro Ohori, Ph.D., research fields: Earthquake engineering. E-mail: ohorim@u-fukui.ac.jp.

tensor elements $M_{pq}(x_s, \tau)$ $(p, q = x, y, z)$ and Green's tensor spatial derivative elements $G_{ip,q}(x_o, t \mid x_s, \tau)$.

$$u_i(x_o, t) = M_{pq}(x_s, \tau) * G_{ip,q}(x_o, t \mid x_s, \tau) \tag{1}$$

Hereafter, I abbreviate $u_i(x_o, t)$, $M_{pq}(x_s, \tau)$, and $G_{ip,q}(x_o, t \mid x_s, \tau)$ as u_i, M_{pq} , and $G_{ip,q}$. Explicit expressions of M_{pq} for a double-couple point source are available in the literature [9]. Considering symmetrical conditions ($M_{pq} = M_{qp}$) and no volume change [$M_{xx} = -(M_{yy}+M_{zz})$] of the moment tensor elements, we can rewrite Equation (1) as

$$u_i = \sum_{j=1}^{5} M_j * G_{ij} \tag{2}$$

where M_j ($j = 1,2,\ldots,5$) is defined by $M_1 = M_{xy}$, $M_2 = M_{yy}$, $M_3 = M_{yz}$, $M_4 = M_{yz}$, $M_5 = M_{zz}$, and G_{ij} ($j = 1,2,\ldots,5$) is defined by $G_{i1} = G_{ix,y} + G_{iy,x}$, $G_{i2} = G_{iy,y} - G_{x,x}$, $G_{i3} = G_{iy,z} + G_{iz,y}$, $G_{i4} = G_{ix,z} + G_{iz,x}$, $G_{i5} = G_{iz,z} - G_{ix,x}$. In a moment tensor inversion, u_i and G_{ij} are given and M_j are the unknowns to be solved in a least-squares sense. Conversely, in the EGTD inversion, u_i and M_j are given and G_{ij} are the unknowns to be solved. Note that the EGTD inversion is carried out for each component at each station using data from several events simultaneously, whereas the moment tensor inversion is computed for a particular event using data of all possible components at all possible stations simultaneously. It should also be emphasized that the moment tensor elements are determined by the source parameters while the Green's tensor spatial derivative elements are dependent on the underground structure of the area surrounding both the source and the station.

3. Data

Strong motion records at FKI007, one of the K-NET stations operated by the National Research Institute for Earth Science and Disaster Prevention (NIED), were used. The map in Fig. 1 shows the station and the epicenter locations of the target events. The source locations determined by the Japan Meteorological Agency (JMA) are summarized in Table 1. The focal mechanisms determined by the F-net (NIED) are also shown in Fig. 1. They all are classified as reverse-faulting mechanisms, but strike-slip faulting components are found in most events. Their epicentral distance from the station was between 16.1 km and 30.8 km. I estimated G_{ij}, the EGTD elements of the target station, from these small events. To treat each event as a point source at the same location with different source mechanisms, I conducted, as described below, some corrections to the focal mechanisms and the waveform data prior to EGTD estimation.

As seen in Fig. 1, the sources of the target events are close to each other. The station azimuth, with respect to the epicenters, is between 26.2° and 38.3°. To compensate for this discrepancy, I selected event 2 as a reference event and horizontally rotated the focal mechanisms of the other six events so that the station azimuth of each event can be treated as the same as that of event 2. Fig.2 shows the distributions of moment tensor elements for the seven events after this horizontal rotation. Also, the take-off angle of the station, with respect to each source, varies from 104.5° to 131.4°. In a previous study [5], we examined the effect of vertical rotation of focal mechanisms to correct for differences in takeoff angles and found that this is not significant when epicentral distances are larger than source depths. Therefore, for simplicity, I disregarded this compensation.

The observed acceleration records at FKI007 for the seven small events were integrated into velocity waveform data with a bandpass filter of 1-4 s. Two horizontal components were rotated into transverse and radial ones. According to Ohori and Hisada [5], corner frequencies of all events are expected to be much higher than 1 Hz, so I targeted the frequency components lower than 1 Hz. To adjust the timing among events, I applied a time shift to the observed data to match the S-wave arrival time with that of the reference event 2. Also, for simplicity, I neglected any differences in the source time functions of the events. Differences in the seismic moments among events were corrected by normalization to 1.0 × 10^{15} Nm, approximately equal to M_w4.0.

Table 1 The source information of target events determined by the united hypocenter catalog of the JMA (Japan Meteorological Agency).

Event	Date (y/m/d)	Clock (h:m:s)	Latitude (deg.)	Longitude (deg.)	Depth (km)	M_J
1	2001/4/16	19:05:18.19	35.4737	135.9208	14.30	4.0
2	2001/12/28	3:28:02.73	35.4497	135.8957	6.74	4.2
3	2003/3/13	21:04:56.02	35.5152	135.9773	14.22	4.1
4	2008/8/8	4:35:16.24	35.4213	135.8563	14.56	4.2
5	2008/8/30	18:28:30.11	35.4207	135.8573	14.51	4.2
6	2009/11/22	23:49:22.73	35.4907	135.9105	11.79	3.7
7	2009/11/22	23:52:29.04	35.7920	135.9097	11.83	3.7

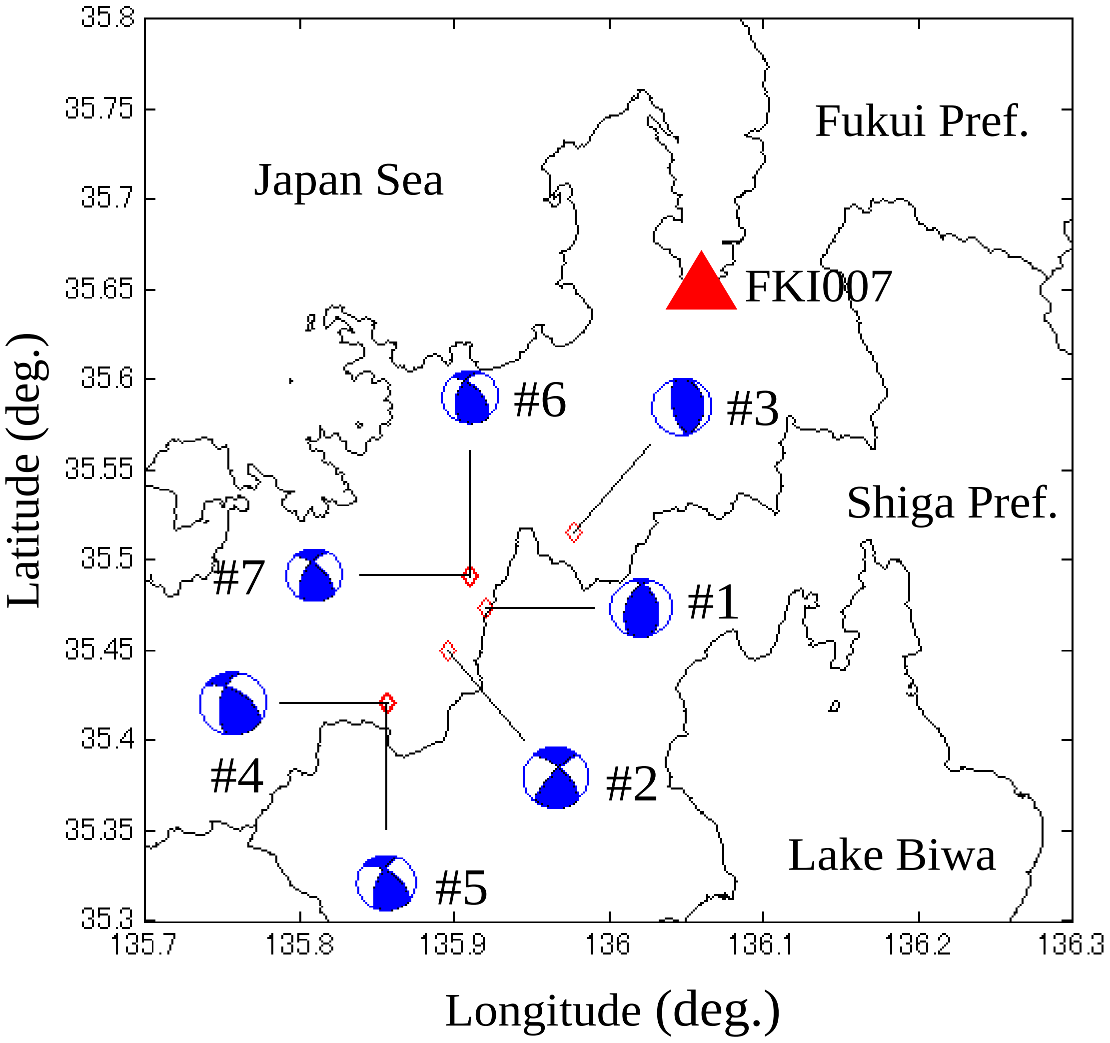


Fig.1 Map showing epicenter locations of small events (M_J 3.7-4.2) and the target station, FKI007. Focal mechanisms, as determined by the F-net, are also shown. Numerals after # show correspondence to the events listed in Table 1.

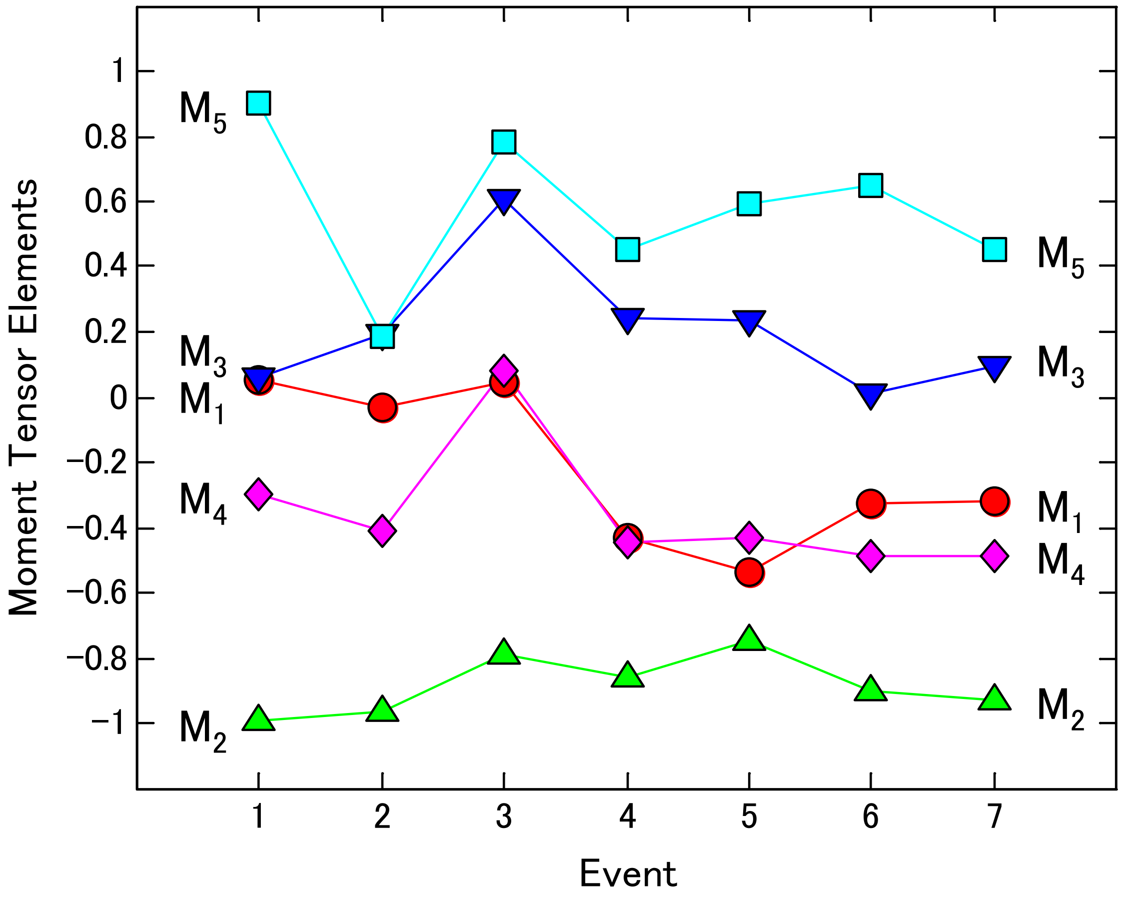


Fig. 2 Distributions of moment tensor elements for seven small events.

4. Results

Through the above procedure, I estimated the EGTD elements as shown in Fig. 3. This shows very long duration characteristics in each EGTD element, after the S-wave main portion. These are difficult to produce by wave propagation theory for a stratified underground structure and reflect the complicated underground structure of the area surrounding both the source and the station. As suggested by Ohori and Hisada [5], the EGTD elements could be useful for the structural study.

In Fig.4, I compare the observed velocity waveforms (thick line in light color) and corresponding syntheses calculated using EGTD (thin line in black). For each trace, the seismic moment of all events was satisfactory for not only the S-wave main portion, but also the S-wave coda portion. From Fig. 4, an acceptable match for the whole waveforms of all events can be found in three components.

The ratio of the maximum amplitude between the synthesized and observed waveforms (hereafter "ratio") agrees well, no more than 1.2 for all events except event 4. The ratios for event 4 were 1.27, 1.20, and 1.43 in transverse, radial, and vertical components, respectively. The overestimation of the three components for event 4 suggests that I could reduce the seismic moment of this event, as estimated by the F-net, down to 80% at least. Conversely, the ratios of event 6 were 0.80, 0.94, and 0.89 in transverse, radial, and vertical components, respectively. The underestimation in three components for event 6 suggests that I should increase the F-net seismic moment of this event to approximately 110%. I will reconsider the correction of seismic moments when I estimate the EGTD of several stations, including FKI007, in a future study. On the whole, I consider that the agreement of the simulation results obtained using the EGTD method with observation data is very good.

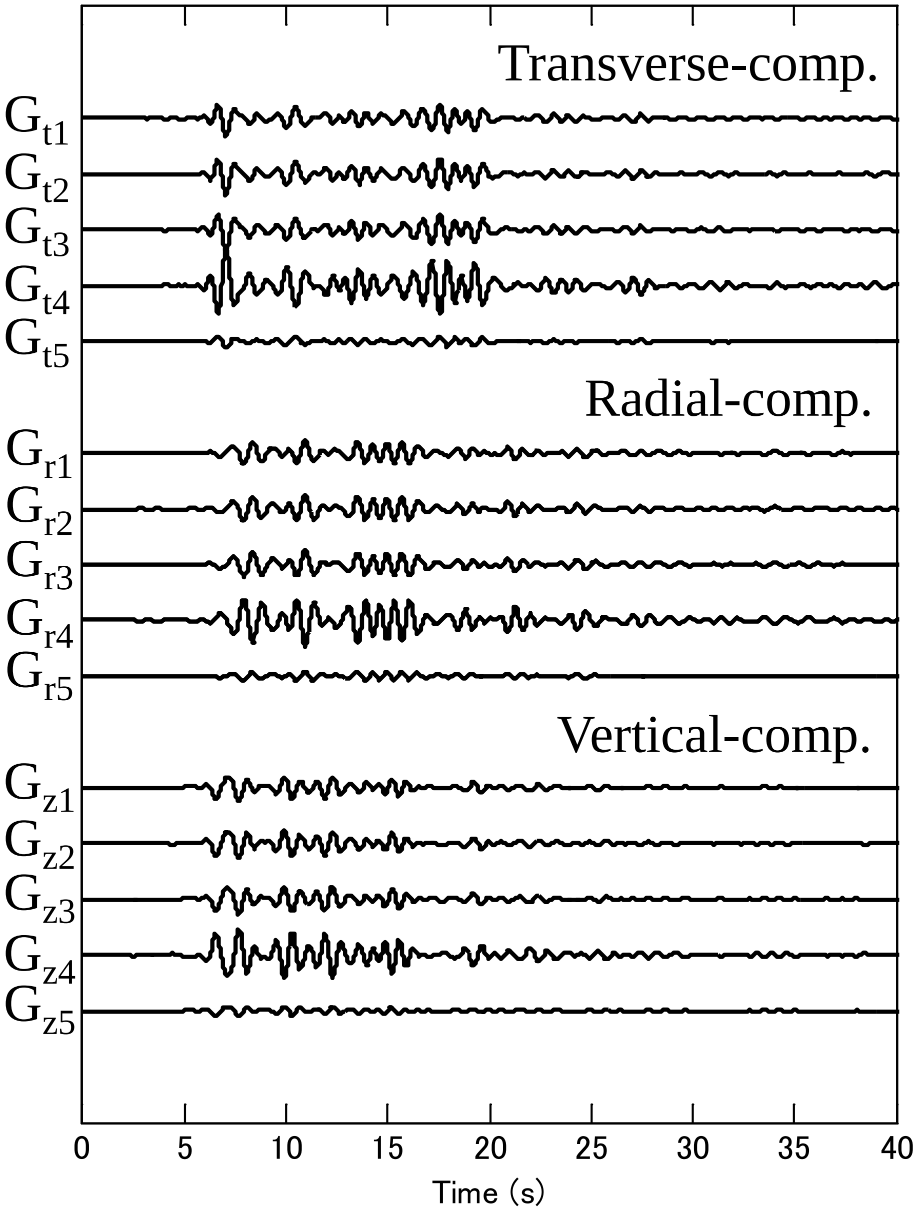
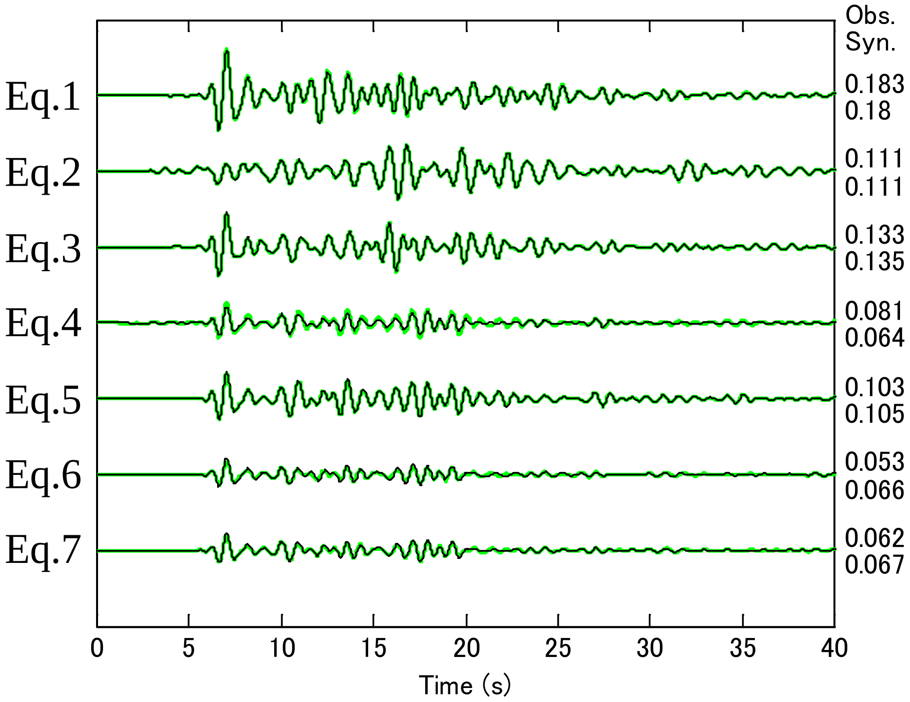
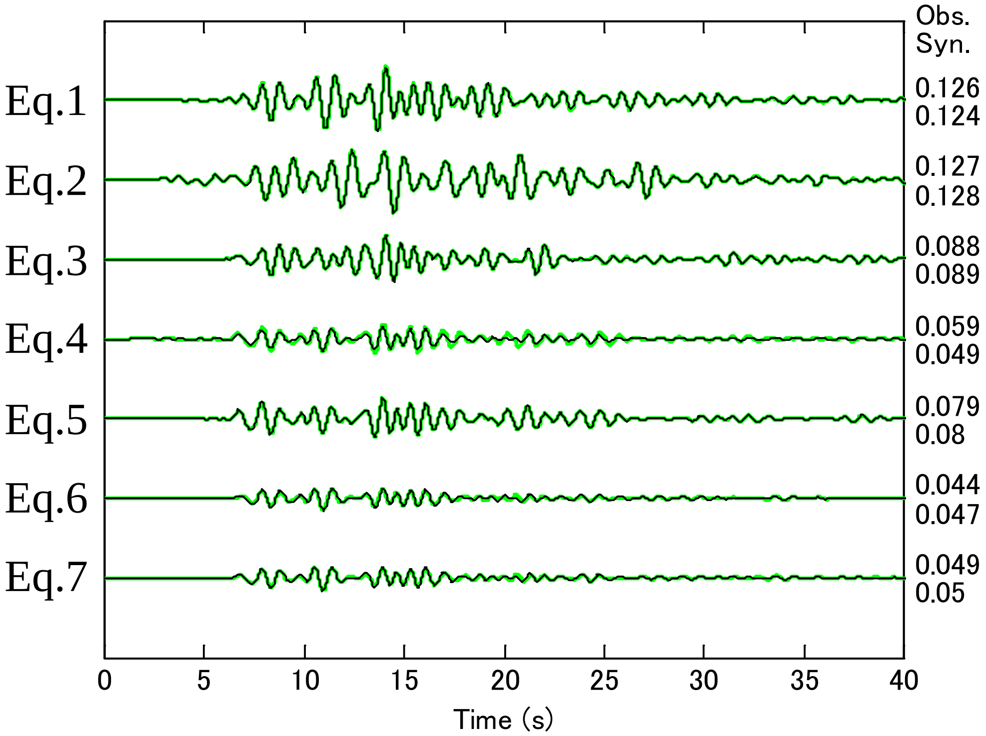


Fig. 3 Estimated results of empirical Green's tensor spatial derivative (EGTD) elements. For graphical purposes, the amplitudes of EGTD vertical components are three times exaggerated compared with the two horizontal components.



(a) Transverse-comp.



(b) Radial-comp.

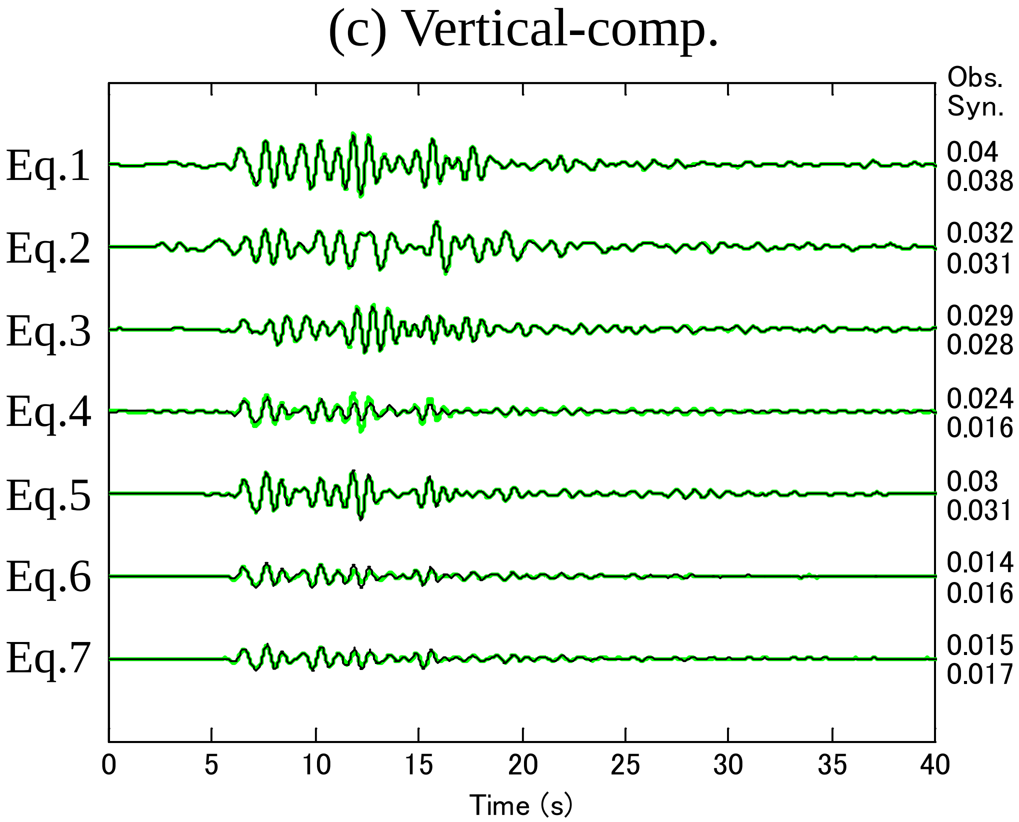


Fig. 4 Comparison of the observed velocity waveforms used in the EGTD estimation (thick line in light-color) and the corresponding syntheses calculated from the EGTD (thin line in black). The absolute peak amplitude (in cm/s) is given at the end of each trace.

5. Conclusions

In this report, I demonstrate the applicability of the EGTD method to simulate near-field strong-motion records for seven small events (M_J 3.7-4.2) that occurred in the southern part of Fukui Prefecture, Japan. I performed EGTD inversion independently for each component for all time-sampling data. Using the estimated EGTD, I simulated the strong ground motion records for these events. The agreement between the observed and calculated waveforms for the all events is satisfactory over a long duration and there is a good match for the amplitude. The EGTD estimates in this report should be confirmed when future earthquakes occur around the same source area. This study targeted components lower than the corner frequencies of all events. Estimation of the broadband EGTD, including frequency ranges higher than corner frequencies, will be investigated in future work [7]. In conclusion, it is noteworthy that this preliminary study in an area of relatively low seismicity is encouraging for the further investigation of EGTD estimation and evaluation of strong motion predictions using EGTD.

Acknowledgements

The strong ground motion data used in this study were recorded at the K-NET stations provided by the National Research Institute for Earth Science and Disaster Prevention (NIED) on their Websites (http://www.k-net.bosai.go.jp/k-net/, last accessed April 2015). The Japan Meteorological Agency (JMA) unified hypocenter catalogue and the F-net source parameters were also provided by the NIED on their Website (http://www.fnet.bosai.go.jp/, last accessed April 2015). This study was partially supported by Grants-in-Aid for Scientific Research (C) (24540464).

References

[1] V. Plicka, J. Zahradnik, Inverting seismograms of weak events for empirical Green's tensor derivatives, Geophysical Journal International 132 (3) (1998) 471-478.

[2] Y. Ito, T. Okada, T. Matsuzawa, N. Umino, A. Hasegawa, Estimation of stress tensor using aftershocks of 15 September 1998 M5.0 Sendai, NE Japan, earthquake, Bull., Earthq. Res. Inst. 76 (2001) 51-59. (in Japanese)

[3] Y. Ito, A study on focal mechanisms of aftershocks, Report of the National Research Institute for Earth Science and Disaster Prevention 68 (2005) 27-89. (in Japanese)

[4] M. Ohori, Y. Hisada, Estimation of Empirical Green's Tensor Spatial Derivatives using Aftershocks of the 2001 Hyogo-ken Hokubu Earthquake and Simulation of Mainshock (M_J5.4) Strong Motion, Zisin 2, 59 (2006) 133-146. (in Japanese with English abstract)

[5] M. Ohori, Y. Hisada, Comparison of the empirical Green's spatial derivative method empirical Green's function method, Bull. Seism. Soc. Am.101 (2011) 2872-2886.

[6] N. Pulido, L. Dalguer, H. Fujiwara, Strong motion simulation on a dynamic fault rupture process and empirical Green's tensor derivatives, Fall Meeting of the Seismological Society of Japan, D018, 2006.

[7] M. Ohori, Simulation of broadband strong motion based on the empirical Green's spatial derivative method, Second Conference on European Earthquake Engineering and Seismology, Istanbul, August 25-29, 2014.

[8] T. Ishibe, K. Shimazaki, Characteristic earthquake model and seismicity around late quarternary active faults Japan, Bull. Seism. Soc. Am. 102 (2012) 1041-1058.

[9] K. Aki, P. G. Richards, Quantitative seismology, theory and methods, W. H. Freeman, San Francisco, 932 (1980).