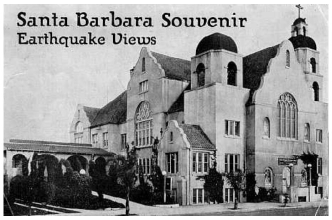

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Strong Ground Motion Simulation of the October 22, 1999 Chiayi Earthquake Using Hybrid Green's Function Method

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ABSTRACT

The objective of this paper is to simulate the ground motions of the Chiayi earthquake (M_L=6.4) in 1999 by using the hybrid Green's function (HGF) method (Kamae *et al*., 1998). The method is designed to combine the advantages of both deterministic and stochastic approaches on broadband ground motion simulations. In this study, we use the discrete wavenumber method (Bouchon, 1981) for low-frequency part ($f \leqq$ 1Hz), and the stochastic simulation technique (Boore, 2003) for the high frequency part (f>1Hz). First, we establish the one-dimensional velocity models at the used sites for the Green's function calculation according to the crustal velocity structure (Ho, 1994) and the near-surface velocity structure (Wu and Huang, 2011) of the Chiayi area. Based on the point source model, the synthetic Green's function is calculated for the small event. Then we combine the low- and high-frequency part of the simulated waveforms. Finally, we choose the source model by Huang *et al*. (2000) and simulate the ground motions of the mainshock by the summation of the HGFs following the empirical Green's function method. The simulated motions in time and frequency domain are similar to the observed ones. It shows that the HGF method provides a good alternate for the ground motion simulation while the small event is unavailable.

DATA AND SITE

On 22 October, 1999, a damage earthquake (ML=6.4) occurred near Chiayi City in southwestern Taiwan. In this paper, we apply the hybrid Green's function (HGF) approach to simulate the ground motions of the Chiayi earthquake. First, the synthetic Green's function of a small event is calculated by combining the low- and high-frequency motions. Then the strong ground motions of a large earthquake are obtained by summation of the HGFs following the empirical Green's function method (EGF). Because the similar source mechanism between the larger and the small earthquake is necessary, one aftershock (M_L5.1) is selected to as the element event and to simulate ground motion of the target event (mainshock, M_L6.4). The fault plane solutions of these two events (Huang *et al*., 2000) are summarized in Table 1. Figure 1 shows the locations of the epicenters of the Chiayi mainshock and one aftershock (M_L5.1) that occurred on 23 October 1999. Many strong-motion stations (CHYxxx) located at the Chiayi area were triggered by these two events. We select eight stations of them and shown in Fig. 1. Besides, Wu and Huang (2011) have inverted the shallow 1-D velocity models from microtremor array recoeds at these eight sites.

ANALYSIS METHOD

The EGF method (Irikura, 1986) is one of the simplest techniques that well represents for the source, path and site effects in broad frequency band. Although the EGF method will retain the characteristics of seismic wave in high-frequency band, the limitations still exist in some cases. Basically, the focal mechanism of the target event should be similar to that of the element event. Besides, the records of the element event are with high S/N ratios. However, it is not easy to satisfy these two conditions. Therefore, we use a hybrid scheme that combines the advantage of deterministic and stochastic approach for small event modeling. Figure 2 presents the flow chart of the HGF method. The low-frequency part (f≦1 Hz) is calculated by discrete wavenumber method (Bouchon, 1981, 2003) assuming a point source model. The high-frequency part (f＞1 Hz) is calculated using the stochastic simulation technique (Boore, 2003) which is also based on a point source model. Moreover, we combine both the low- and high-frequency waves of the small event in the time domain. Finally, the large event simulations are obtained by summation of the resultant HGFs performed by EGF method. The synthetic motion *U(t)* for the large event is given using the observed record *u(t)* for the small event as (Irikura, 1986; Miyake *et al*., 1999)

$$U(t) = \sum_{i=1}^{N}\sum_{j=1}^{N}(r/r_{ij}) \cdot F(t) * (C \cdot u(t)) \qquad (1)$$

where r_{ij} represents focal distance for (*i,j*) element and *N* is the scaling parameter. Correction function *F(t)* is to adjust a difference in slip velocity between the mainshock and the small event. This function is expressed as the sum of a delta function and a boxcar function. *C* is the stress drop ratio between the mainshock and a small event.

RESULTS AND DISCUSSIONS

While the synthetic waveforms of a small event are calculated, we need to build up some source parameters first. According to the empirical relationships (e.g., Lin and Lee, 2008; Hanks and Kanamori, 1979; Durukal and Catalyurekli, 2004; Brune, 1971; Somerville *et al*., 1999), we estimate the theoretical source parameters of the small event which include moment magnitude, seismic moment, corner frequency, stress drop, rise time and asperity size. These parameters are tabulated in Table 2. Besides, we establish one-dimensional velocity models (Fig. 3) at the used sites according to the crustal velocity structure (Ho, 1994) and the near-surface velocity structure (Wu and Huang, 2011) of the Chiayi area. For the propagation path effect, we choose the Q value estimated by Ji (2006). In addition, the site amplification due to the near-surface sedimentary structure is also considered on simulation. The Green's functions are corrected for the local site effect by using the transfer function from Haskell method (Haskell, 1962) at each used site. Here we choose the synthetic results at CHY037 site as an example. Figure 4 shows the low frequency (f≦1 Hz) result of the small event by using the discrete wavenumber method based on the point source model. On the other hand, the high frequency (f＞1 Hz) ground motions of the small event are calculated by the stochastic method and shown in Fig. 5. Finally, the HGFs are obtained at each site by summing the low- and high- frequency parts in the time domain.

Figure 6 shows the source rupture model of the Chiayi mainshock proposed by Huang *et al*. (2000). From the waveform simulations, they got the asperity size is about 4.2 km length in the strike direction by 4.2 km width in the dip direction. The rupture started at the left-bottom of the asperity and extended radially to the right-upper direction when the mainshock happened. They also mentioned the stress drop ratio *C* and the scaling parameter *N* of the mainshock to the aftershock are 1.5 and 3, respectively. Based on this source model, the synthetic waveform of the small event is selected as the input motion to simulate the mainshock record using the summation procedure of the EGF method (Irikura, 1986). The comparison of the observed and synthetic waveforms (NS component) of acceleration, velocity and displacement for the Chiayi mainshock at three stations (CHY037, CHY039 and CHY073) is shown in Fig. 7. There is a good agreement between the main characteristics of observed and simulated ground motions although some waveforms are underestimated or overestimated. According to the above results, the HGF method provides a good alternate for the ground motion simulation at the Chiayi area.

REFERENCES

Boore, D. M. [2003], "Simulation of ground motion using the stochastic method", Pure Appl. Geophys., Vol. 160, pp. 635-676.

Bouchon, M. [1981], "A simple method to calculate Green's functions for elastic layered media", Bull. Seism. Soc. Am., Vol. 71, No. 4, pp. 959-971.

Bouchon, M. [2003], "A review of the discrete wavenumber method", Pure Appl. Geophys., Vol. 160, pp. 445-465.

Brune, J. N. [1971], "Tectonic stress and the spectra of seismic shear waves from earthquakes", J. Geophys. Res., Vol. 75, No. 26, pp. 4997-5009.

Durukal, E., and Y. Çatalyürekli [2004], "Spectral analysis of source parameters of the 1999 Kocaeli and Duzce earthquake aftershock sequences", *Proc. of the 13th World Conference on Earthquake Engineering*, Vancouver, Canada, 421.

Hanks, T. C. and H. Kanamori [1979], "A moment-magnitude scale", J. Geophys. Res., Vol. 84, No. B5, pp. 2348-2350.

Haskell, N. A. [1962], "Crustal reflection of plane P and SV waves", J. Geophys. Res., Vol. 67, No. 12, pp. 4751-4768.

Ho, M. Y. [1994], "*Three dimensional velocity structure of Western Taiwan*", Master thesis, National Central Univ., Taiwan. (in Chinese with English abstract)

Irikura, K. [1986], "Prediction of strong acceleration motions using empirical Green's function", *Proc. 7th Japan Earthq. Engnrg. Sympo.*, Tokyo, Japan, 26.

Kamae, K., K. Irikura, and A. Pitarka [1998], "A technique for simulating strong ground motion using hybrid Green's function", Bull. Seism. Soc. Am., Vol. 88, No. 2, pp. 357-367.

Ji, Z. J. [2006], "*The distribution of Q value in Chia-Nan area, Taiwan*", Master thesis, National Chung Cheng Univ., Chiayi, Taiwan. (in Chinese)

Lin, P. S. and C. T. Lee [2008], "Ground-Motion attenuation relationships for subduction-zone earthquakes in Northeastern Taiwan", Bull. Seism. Soc. Am., Vol. 98, No. 1, pp. 220-240.

Somerville, P., K. Irikura, R. Graves, S. Sawada, D. Wald, N. Abrahamson, Y. Iwasaki, T. Kagawa, N. Smith, and A. Kowada [1999], "Characterizing crustal earthquake slip models for the prediction of strong ground motion", Seism. Res. Lett., Vol. 70, No. 1, pp. 59–80.

Huang, H. C., H. Miyake, T. Iwata, and K. Irikura [2000], "The preliminary results of strong ground motion simulation of the Chia-Yi earthquake of October 22, 1999, using empirical Green's function method", *Proc. 8th Taiwan Geophys. Res. Sympo.*, Taipei, Taiwan, 9-16.

Wu, C. F. and H. C. Huang [2011], "Imaging of shallow S-wave velocity structures in the Chia-Yi area, Taiwan using microtremor array measurements". (to be submitted)

Table 1. Focal mechanisms and source parameters for the Chiayi mainshock and its aftershock used in the study (Huang *et al*., 2000)

Event	Time (UT)	M_L	M_W	Depth (km)	Fault Plan Solution		
					Strike (°)	dip (°)	rake (°)
Mainshock	1999/10/22 02:18:56	6.4	6.15	17.8	206	40	86
					31	50	93
Aftershock	1999/10/23 17:08:02	5.1	4.87	12.7	177	63	63
					45	37	131

Table 2. Theoretical source parameters for ML 5.1 earthquake

Source parameters	Aftershock 1999/10/23 17:08:02
Local Magnitude (M_L)	5.1
Moment Magnitude (M_W)	4.87
Seismic Moment (M_0) (dyne-cm)	2.29×10^{23}
Corner Frequency (f_c) (Hz)	1.2
Stress Drop (△σ) (bar)	79.7
Rise Time (T_R) (sec)	0.124
Rupture Area (A_l) (km^2)	1.36

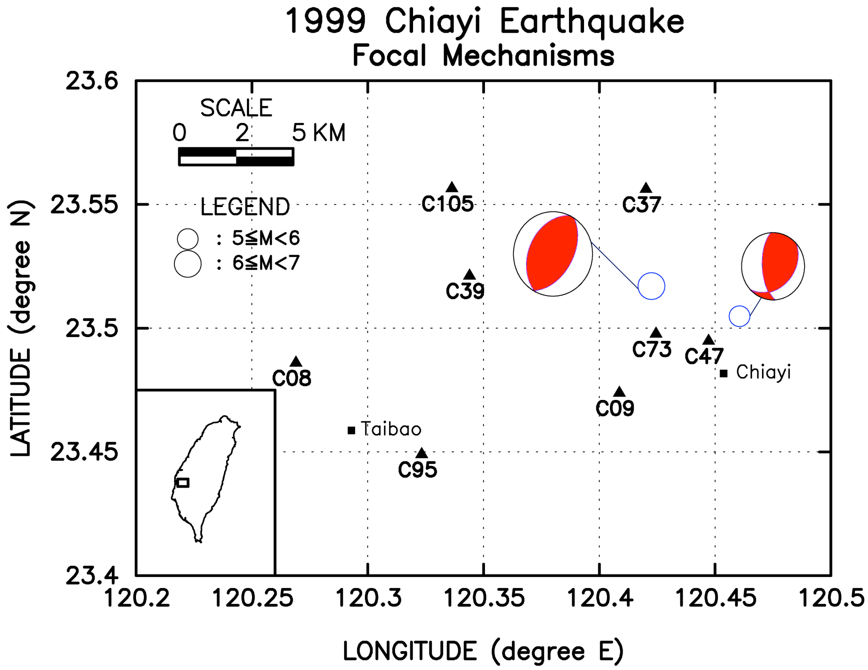

Fig. 1. Map sketching locations of epicenters of the Chiayi mainshock and its aftershock and eight used CHY stations simultaneously triggered by these two events. The focal mechanisms of the Chiayi mainshock and its aftershock are also shown here.

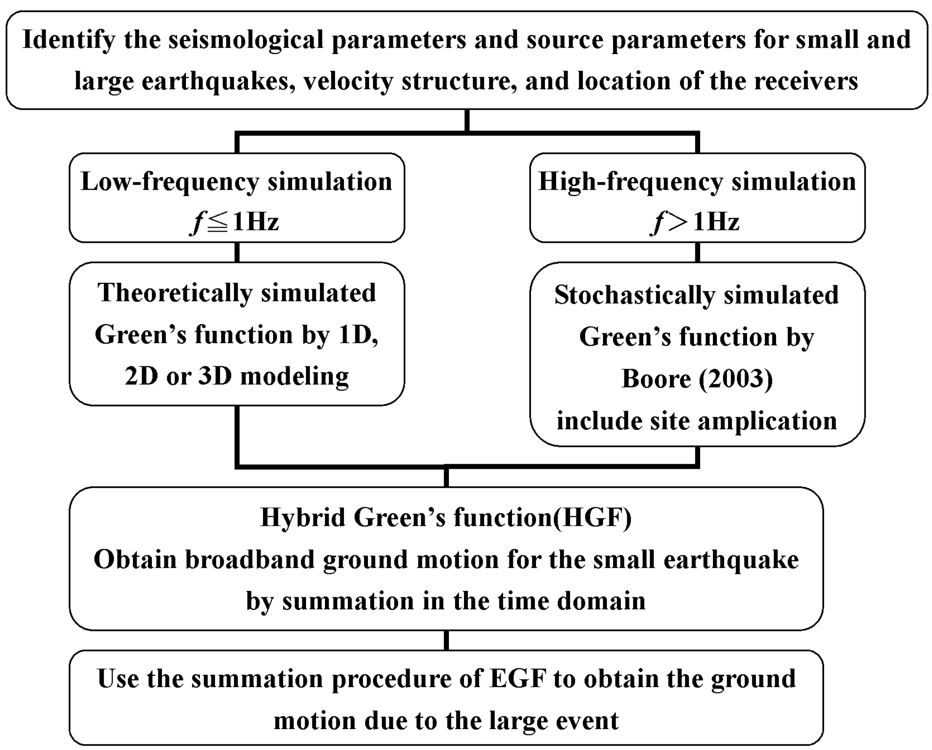

Fig. 2. Flow chart for generating strong ground motion by the HGF technique.

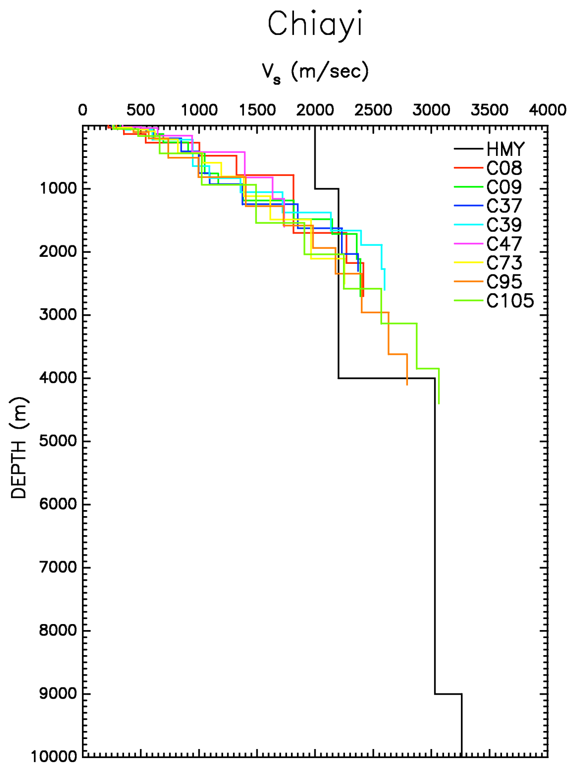

Fig. 3. 1-D S-wave velocity model at the used sites. Black line (HMY) denotes the crustal velocity structure of western Taiwan (Ho, 1994). Colored lines mark the shallow velocity structures at eight used sites inverted from the microtremor array records (Wu and Huang, 2011).

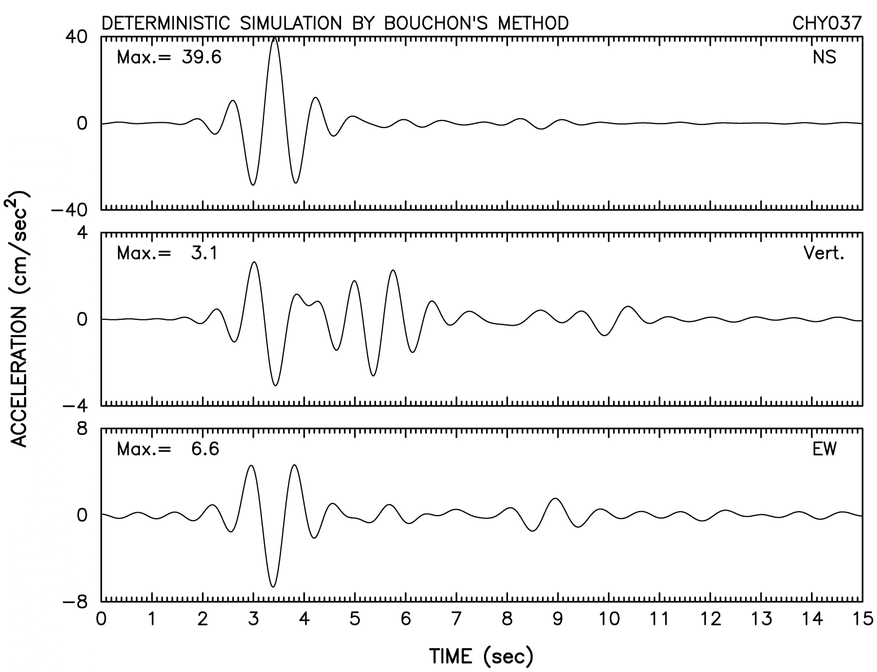

Fig. 4. Based on the point source model, low-frequency simulation calculated by using the discrete wavenumber method (Bouchon, 1981, 2003) at site CHY037.

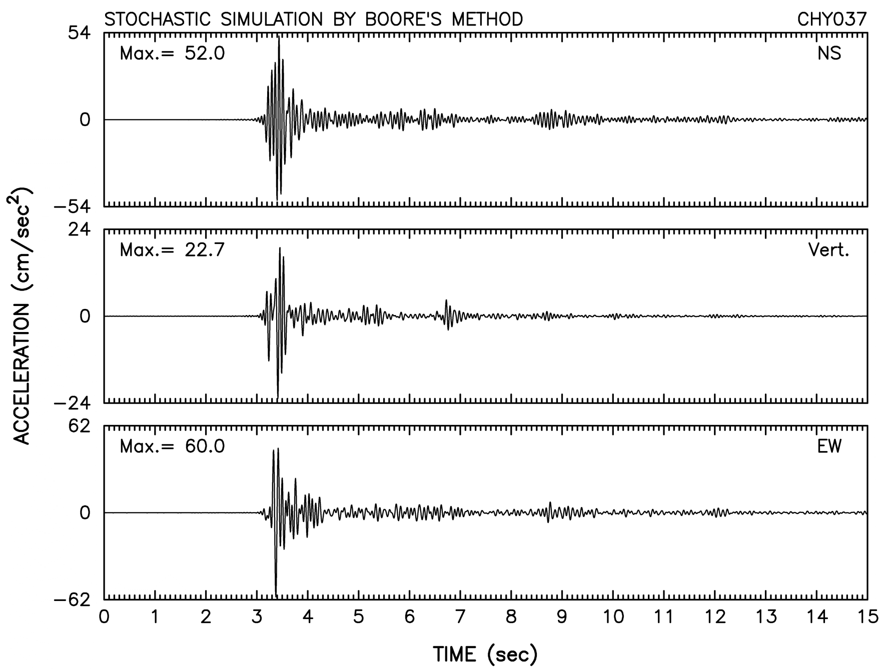

Fig. 5. Based on the point source model, high-frequency simulation calculated by using the stochastic simulation technique (Boore, 2003) at site CHY037.

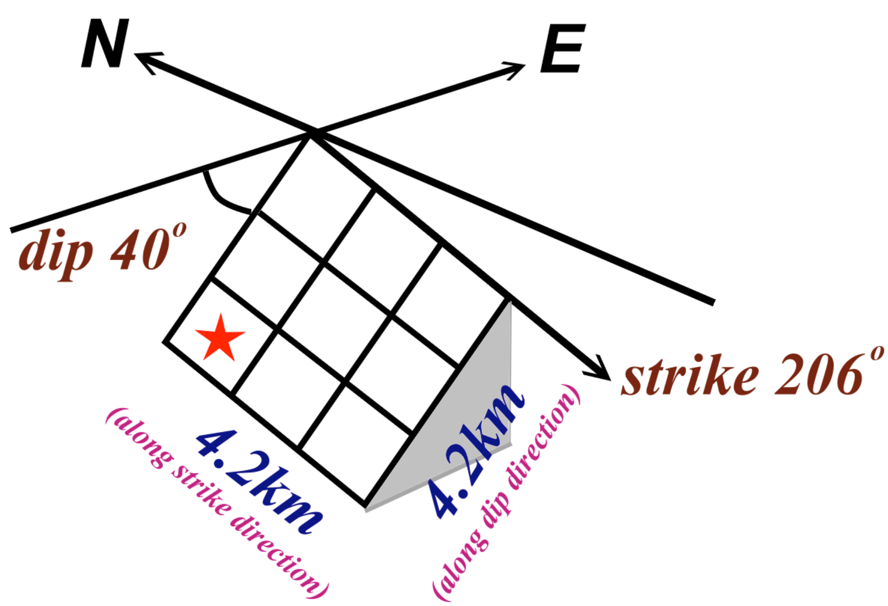

Fig. 6. Source rupture model of the October 22, 1999 Chiayi mainshock (Huang et al., 2000).

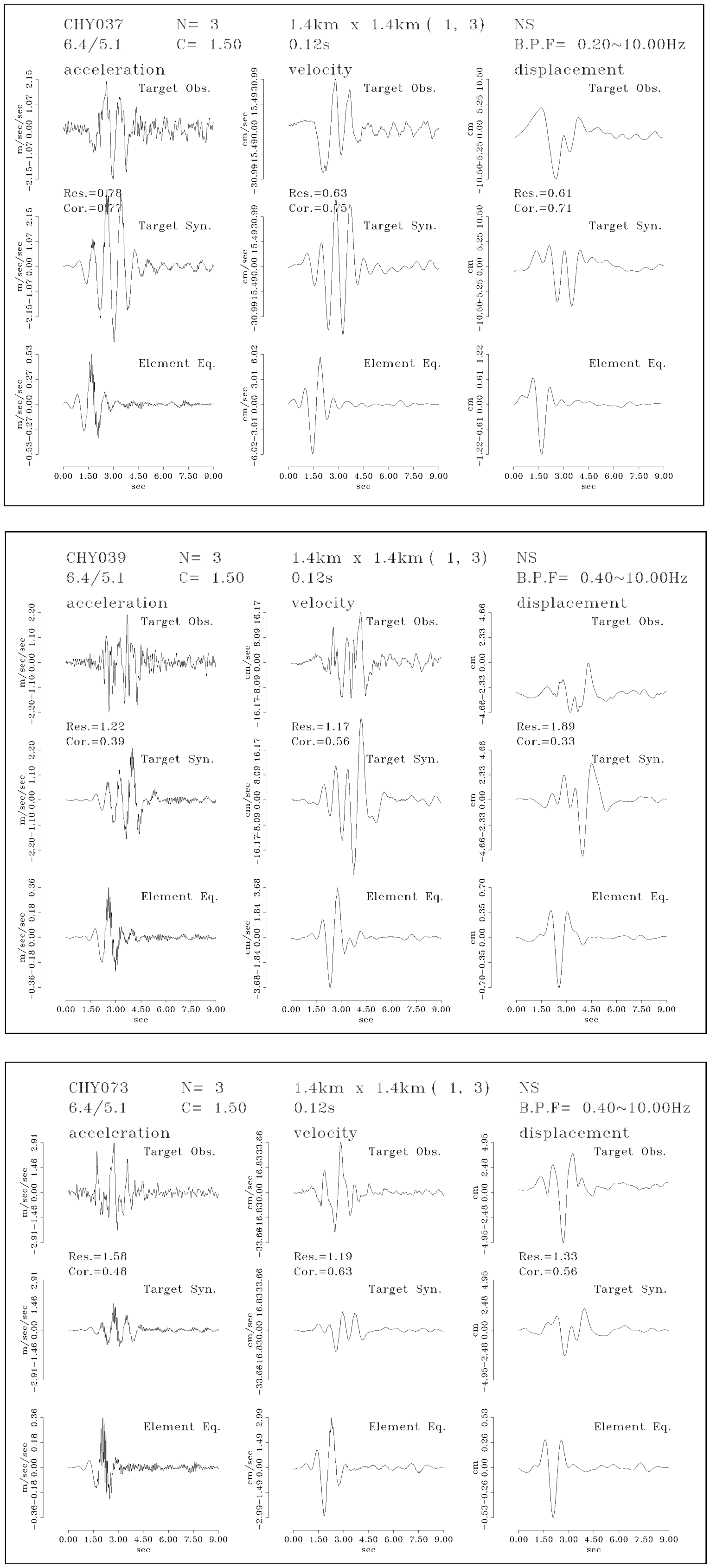

Fig. 7. Comparison of the observed and synthetic waveforms (NS component) of acceleration, velocity and displacement for the Chiayi mainshock at three used stations (CHY037, CHY039 and CHY073).

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