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STUDY ON THE STRONG GROUND MOTION PREDICTION METHOD BY HERP, JAPAN, TO 2010 MW8.8 MAULE EARTHQUAKE, CHILE

Saruul Dorjpalam[1], Yasuo Okada[2], Kiyoshi Irie[3], and Haruhiko Torita[2]

[1] Research Engineer, Ohsaki Research Institute, Inc., Tokyo, Japan (saruul@ohsaki.co.jp)
[2] Deputy Director, Ohsaki Research Institute, Inc., Tokyo, Japan
[3] Principal Researcher, Ohsaki Research Institute, Inc., Tokyo, Japan

ABSTRACT

The Strong Ground Motion Prediction Method by the Headquarters for Earthquake Research Promotion (HERP) is widely practiced in Japan for strong ground motion estimations. The method has been validated by many studies of past earthquakes, mostly crustal earthquakes which occurred in Japan and outside Japan. However, the validation studies of inter-plate earthquakes especially outside Japan are still limited. In this study we investigate the applicability of the method to the inter-plate earthquakes outside Japan on the example of the 2010 Mw8.8 Maule megathrust earthquake, Chile. For that, firstly, we characterize the fault rupture of the 2010 Maule earthquake using the asperity model following the method by HERP. Next, based on the asperity model we simulate strong ground motions using EGF (empirical Green's function) and SGF (stochastic Green's function) techniques. The simulated ground motions are then compared with the recorded strong ground motions of the 2010 Maule earthquake. In overall the fault models could reproduce the recorded strong ground motions fairly well.

INTRODUCTION

In Japan the Strong Ground Motion Prediction Method by the Headquarters for Earthquake Research Promotion (HERP) is widely practiced for strong ground motion estimations using asperity models. The method is also called the Recipe for Strong Ground Motion Prediction, or the Recipe in short. The Recipe has been validated by many studies of past earthquakes, mostly crustal earthquakes, which occurred in Japan and outside Japan. However, the validation studies of inter-plate earthquakes especially outside Japan are still scarce. Accurate estimation of potential threat from large inter-plate earthquakes is important for disaster mitigation especially that of important infrastructure. In this study we investigate the applicability of the Recipe to the inter-plate earthquakes outside Japan on the example of the 2010 Maule megathrust earthquake, Chile.

The mainshock (Mw 8.8) of the Maule earthquake occurred on February 27, 2010 on a plate boundary along the Chilean subduction zone, rupturing approximately 500 km of the mega-thrust interface between two plates, the Nazca plate subducting beneath the South American plate. The event caused substantial damage on land as well as produced extensive tsunami.

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For the estimation of the strong ground motion from a particular seismogenic area, defining the possible seismic source is crucial. In the Recipe method the seismic source is modelled by so-called characterized source model. The characterized source model is comprised of asperities, which are the areas where the fault slips the most and where the built-up stress is released the most, therefore it is also called the asperity model. The adequacy of the Recipe method in modelling the seismic source can be examined by computing the ground motions using various calculation techniques, including empirical Green's function (EGF), stochastic Green's function (SGF) and other techniques, and then comparing the results with the observed ground motion records.

In this study, firstly, we define the asperity model for the 2010 Maule earthquake following the Recipe. Next, we simulate strong ground motions by EGF technique, which uses records from aftershocks to recreate the records of the mainshock. Then, we simulate the strong ground motions for the fault models by SGF technique for stations for which the aftershock recordings are unavailable. Finally, we compare he synthetic results with the records.

STRONG MOTION DATA

The strong ground motion records used in this study are from the University of Chile, Department of Civil Engineering RENADIC network (http://terremotos.ing.uchile.cl/2010), and the Department of Geophysics GUC network (http://evtdb.csn.uchile.cl/). For the mainshock data (February 27, 2010 Mw8.8 event) we used records at five stations (MAR, CURI, CCSP, CONC and ANGO), and for the aftershock data we used records at three stations (MAR for February 27, 2010 Mw6.2 event (aftershock 1); CURI for February 28, 2010 Mw6.2 event (aftershock 2); CCSP for March 25, 2012 Mw7.1 event (aftershock 3)). The records at the stations MAR, CURI, CONC and ANGO from RENADIC network were pre-processed with 0.25Hz-23Hz band-pass filter, and the records at the station CCSP from GUC network were not filtered and were usable for frequency above about 0.1Hz. The locations of the mainshock, the aftershocks and the stations are shown in Figure 2 in the next section.

FAULT MODELING

The source of the 2010 Maule mega-thrust earthquake was modelled using the asperity model. Here we briefly describe the general procedure of fault modelling by the Recipe and the application of the procedure to set up the asperity model for the 2010 Maule earthquake.

Strong Ground Motion Estimation Method By HERP (The Recipe)

According to the Recipe, as shown in the flowchart in Figure 1, the asperity model for the inter-plate earthquakes are set up using six main fault parameters, which include source fault area S, averaged stress drop $\Delta\sigma$, asperity area S_{asp}, stress drop on asperity $\Delta\sigma_{asp}$, seismic moment M_0, and short period level A. Given the size of the earthquake, which can be expressed by the seismic moment M_0 or fault area S, the rest of the fault parameters can be calculated using empirical relations between seismic moment and fault area, between seismic moment and short period level, and other general equations shown in the flowchart.

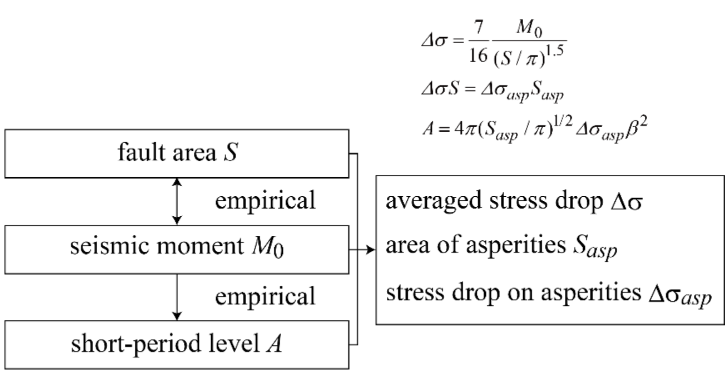

Figure 1. Procedure for setting fault parameters of inter-plate earthquakes for strong ground motion prediction.

The Asperity Model For The 2010 Maule Earthquake

In the asperity model for the 2010 Maule earthquake, first we determined the seismic moment M_0 from the moment magnitude Mw=8.8 using Equation 1 by Kanamori (1977). Then from the empirical relation by Tajima et al. (2013) shown in Equation 2 we estimated the fault area *S*. The short-period level *A* was estimated from the empirical relation by Dan et al. (2001) shown in Equation 3. The remaining parameters were calculated from the formulas on the flowchart in Figure 1.

$$M_0[\mathbf{N}\cdot \mathrm{m}] = 10^{1.5M_W+9.1} \tag{1}$$

$$S[\mathrm{km}^2] = 5.82\times10^{-7}\times(M_0[\mathbf{N}\cdot\mathrm{m}])^{1/2} \tag{2}$$

$$A[\mathrm{N\cdot m}/\,\mathbf{s}^2] = 2.46\times10^{10}\times(M_0[\mathrm{N\cdot m}]\times10^7)^{1/3} \tag{3}$$

The resulting asperity model is shown in Figure 2 and Figure 3.The model consists of four asperities with large stress drop (14MPa) and large slip (14m~10m), and the background area with small stress drop (2.1MPa) and small slip (5.4m). For the location of the asperities we referred to Frankel (2017).

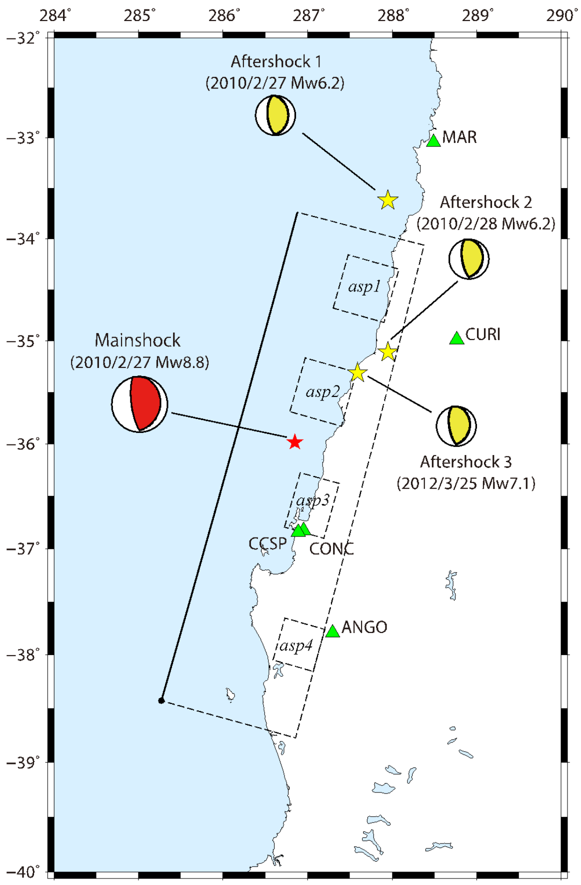

Figure 2. Locations of the mainshock, the aftershocks, the recording stations and the surface projection of the asperity model for 2010 Maule earthquake.
(red star: hypocentre, yellow star: aftershocks, green triangle: stations)

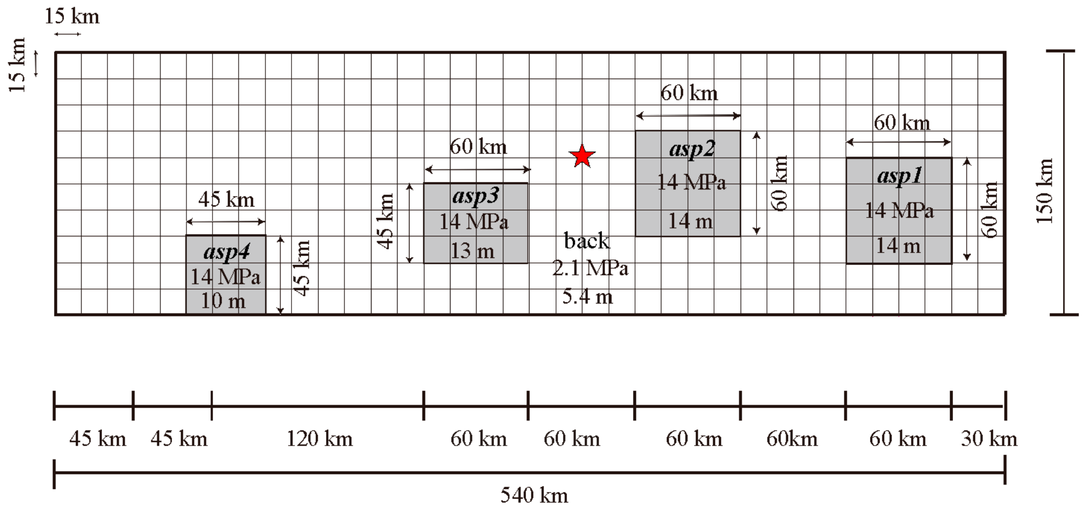

Figure 3. The asperity model for the 2010 Maule earthquake (red star: hypocentre).

The source medium is defined by S-wave velocity Vs=3.65km/s and rigidity μ=3.7GPa, which was based on soil profile used in Frankel (2017).

STRONG MOTION CALCULATION

Using the asperity model ground motions were simulated by EGF and SGF methods. Then the simulated waveforms were compared to the recorded waveforms. EGF method was used for the three stations at which both the mainshock and the aftershock records were available, which are MAR and CURI in the north and CCSP at around centre. Due to unavailability of the aftershock records on the south of the fault SGF method was used in an attempt to reproduce mainshock records at CONC and ANGO stations.

Strong Motion Calculation By EGF (Empirical Green's Function) Method

The synthetic ground motions were calculated using the EGF method by Dan et al. (1989) at three stations (CURI, MAR, CCSP), for which both mainshock and aftershock records were available. This method utilizes smaller event (aftershock or foreshock) records to reproduce the ground motions of a larger event (mainshock, also called target event) by summing up the small event with adjustments. In EGF method the records of a small event is considered to incorporate propagation path and local site effects of a target event.

The acceleration waveforms and the pseudo-velocity (PSV) spectra computed for the three stations are compared with those of the mainshock records in Figure 4~Figure 6. The observation records are plotted in black and the synthetic results are plotted in red. Overall the synthetic results reproduced the observation quite well in terms of the peak values and PSV spectra, especially at CURI station (Figure 4). From the location of CURI in Figure 2, we can see that the records at the station are mostly affected by asperities *asp1* and *asp2*, which might be indicative of adequacy of modelling of these two asperities. On the other hand, although the peak values of the synthetic acceleration waveforms for MAR are quite similar to the observation, the synthetic PSVs at periods longer than around 0.5 sec lack power compared to the observation (Figure 5). The same PSV trend is apparent for CCSP station (Figure 6). The possible reason for the deviation could be associated with the nonlinearity of the soil at the site. Furthermore, the peak values of the synthetic waveforms at CCSP differ from those of the observation. From Figure 2, we can see that CCSP might mostly be influenced by asperity *asp3*. Therefore, the deviation of the synthetic results from the observation might be indicative of deficiency in the setting of asperity *asp3*.

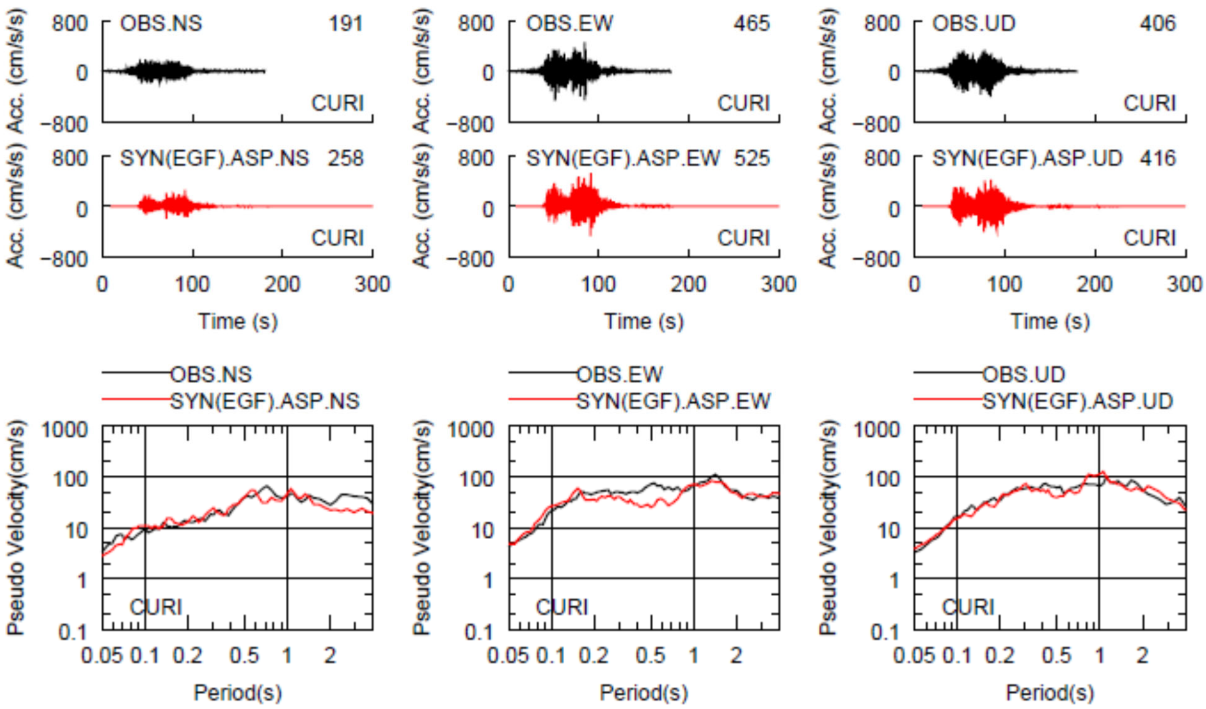

Figure 4. Comparison of synthetic results calculated by EGF method with the observation at CURI.

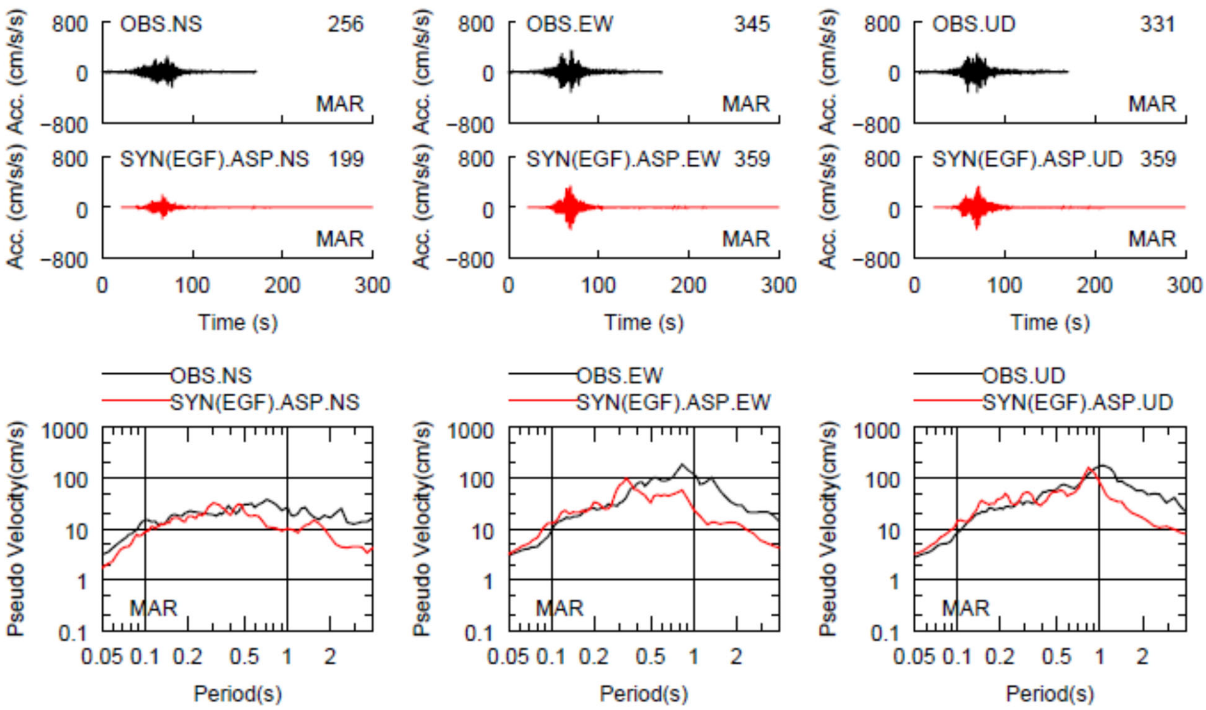

Figure 5. Comparison of synthetic results calculated by EGF method with the observation at MAR.

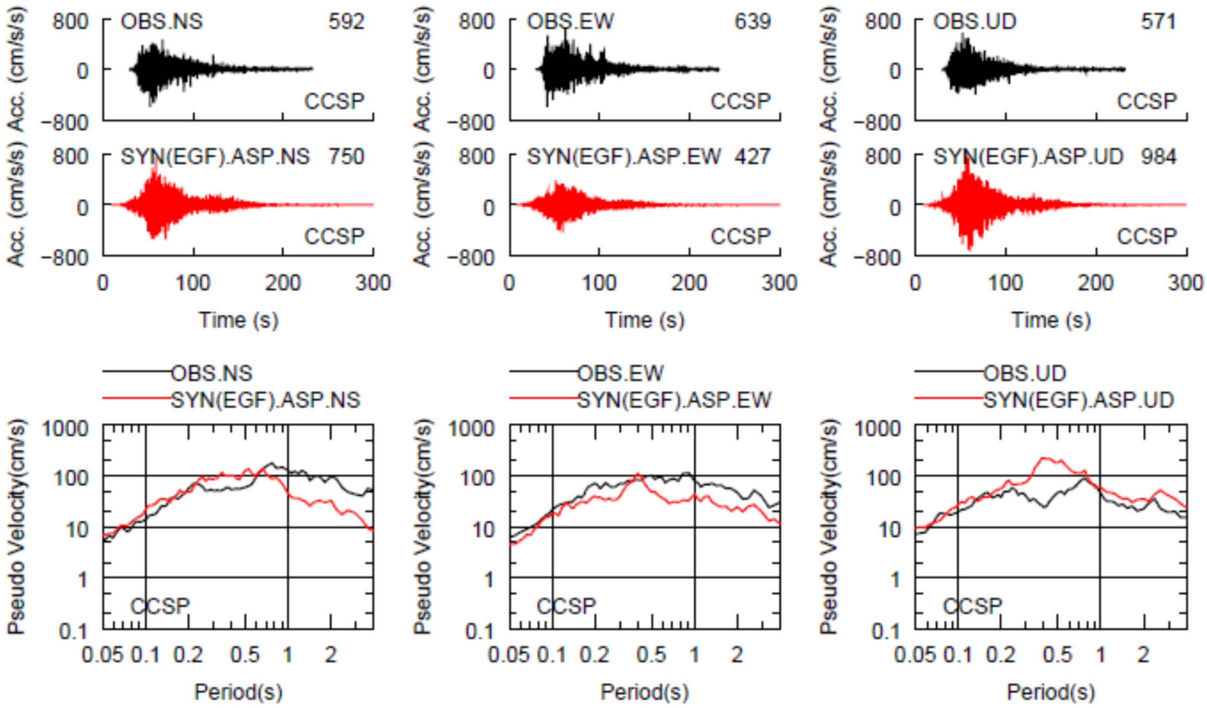

Figure 6. Comparison of synthetic results calculated by EGF method with the observation at CCSP.

Here we need to mention that the synthetic waveforms at CURI were corrected for cut-off frequency f_{max}, where it was set to f_{max}=10Hz for the mainshock and to f_{max}=20Hz for the afterschock 2.

Strong Motion Calculation By SGF (Stochastic Green's Function) Method

The synthetic ground motions at the ANGO and CONC stations on the south of the fault, for which only mainshock records were available were calculated using the SGF method. SGF method is similar to EGF method, the main difference being that the small event records are substituted by the computer-generated time histories. In this study we adopted stochastic Green's function generation method by Boore (1983) and the synthesis method by Dan et al. (1989). The path Q-value was Q=200 $f^{0.69}$ (with constant value below 1 Hz). The frequency-dependent radiation pattern coefficients were adopted in accordance with Satoh (2002) – specifically, for frequencies lower than 3Hz, the theoretical radiation pattern coefficients were adopted, for frequencies higher than 6Hz, the value of 0.445, which is the average of the theoretical radiation pattern coefficients (Boore and Boatwright, 1984), was utilized, and finally for frequencies between 3Hz and 6Hz, the values were linearly interpolated in log-log scale. For the local site effect we adopted velocity model used in Frankel (2017) for deeper soil structure. For shallow soil structures (up to about 50m from surface) we referred to Molnar et al. (2015), University of Chile site (http://terremotos.ing.uchile.cl/), and Chilean Foundation of Geotechnical Research site (http://www.fuchige.cl/). Detailed information on the intermediate depth velocity structure (below 50m and up to seismic bedrock) was not available.

The acceleration waveforms and the pseudo-velocity spectra computed by SGF method for CONC and ANGO stations are plotted in Figure 7 and Figure 8. These stations are the most south located stations with recorded strong motions of the mainshock. The synthetic results for CONC station, which is located close to asperity *asp3*, overestimate the observation at lower periods and underestimate at longer periods, which might be a further proof that *asp3* shall be reassessed. The synthetic results for ANGO station

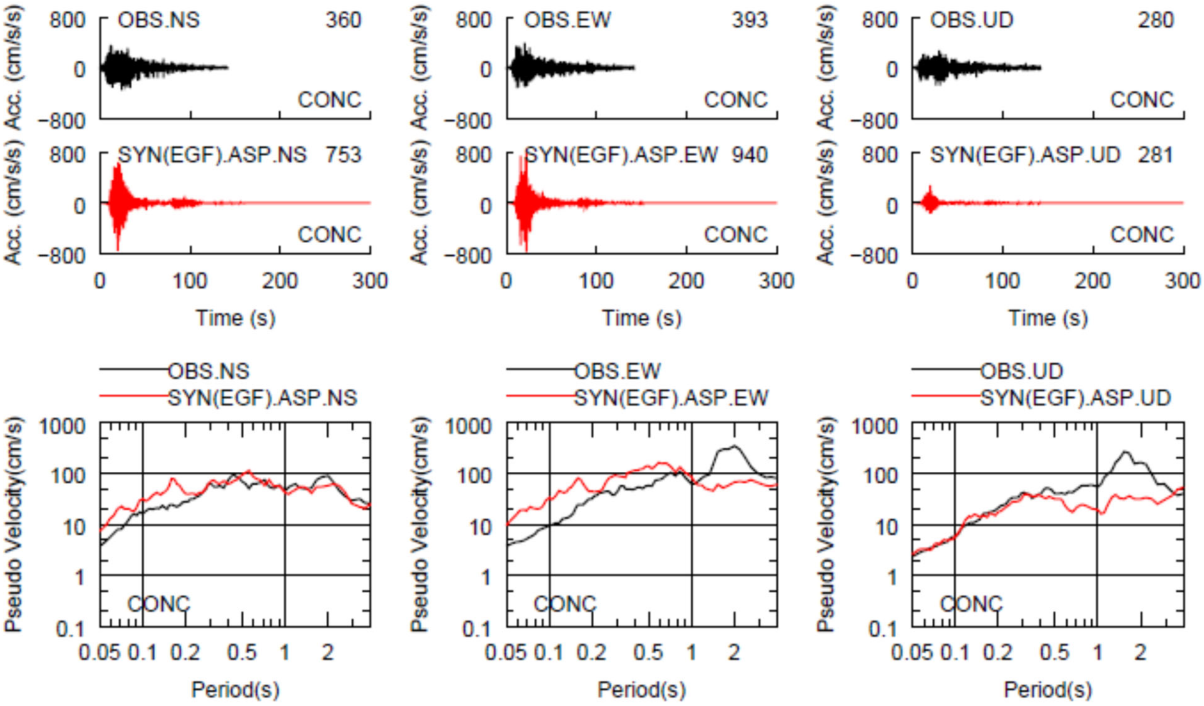

Figure 7. Comparison of synthetic results calculated by SGF method with the observation at CONC.

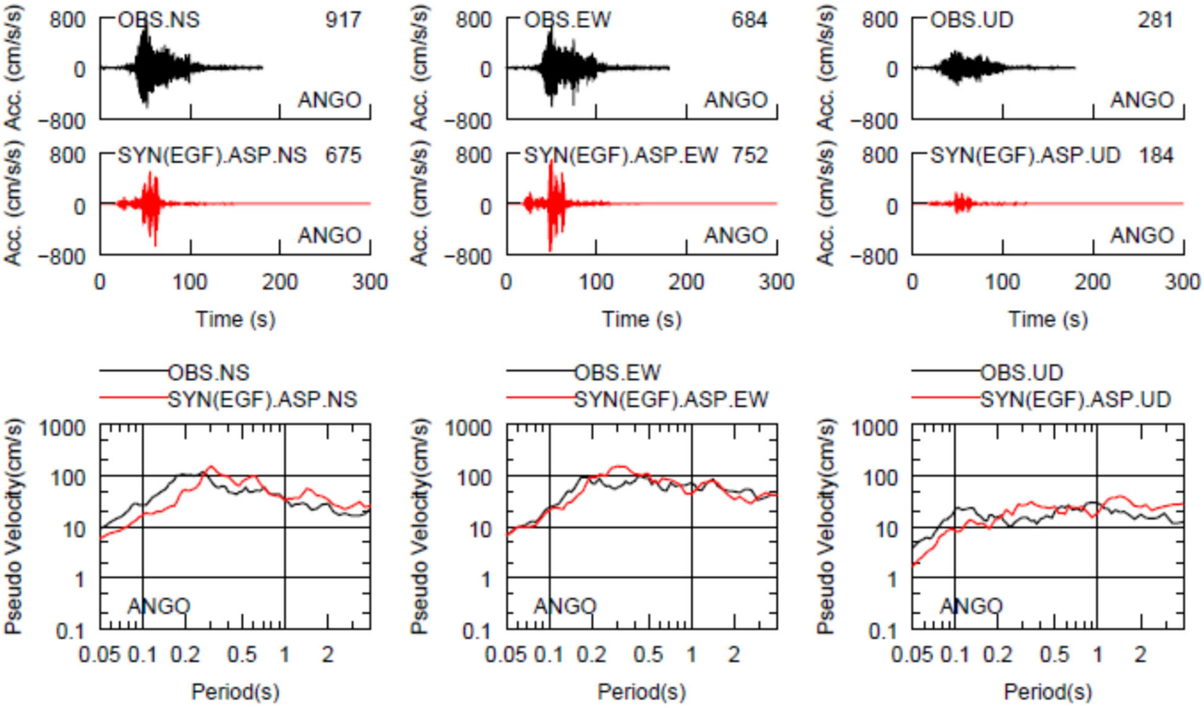

Figure 8.Comparison of synthetic results calculated by SGF method with the observation at ANGO.

perform better than CONC, although better fit is desirable. The poor performance of the synthetic results at both stations might be affected by insufficient reflection of the site effect. Adequate soil velocity is essential in SGF method.

CONCLUSION

In this study we investigated the applicability of the Strong Ground Motion Prediction Method by the Headquarters for Earthquake Research Promotion (HERP), Japan, to the inter-plate earthquakes outside Japan on the example of the 2010 Mw8.8 Maule megathrust earthquake, Chile. We formulated the asperity model for the Maule earthquake according to the above method by HERP, calculated ground motions using empirical and stochastic Green's function techniques, and examined the results against the recorded waveforms. In overall the asperity model could reproduce the observation records fairly well. Further refinement of the asperity model is desirable especially in the setting of the two asperities on the south part of the fault. Also, clarification of the specifics of the underestimation at longer periods is needed.

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