SIMULATION OF STRONG MOTION AT KASHIWAZAKI DURING THE 2007 NIIGATAKEN CHUETSU-OKI, JAPAN, EARTHQUAKE

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ABSTRACT :

In this study, we evaluated the strong motion on engineering bedrock at a K-NET station NIG018, based on the Empirical Green's function method. For verifying the results, we calculated the response wave on surface using a dynamic effective stress method, and compared the synthetic seismic waves with the observed ones. The results show that the synthetic waves matches the observed ones well in response spectra, implicating that the amplitude of the synthetic wave on the engineering bedrock are adequate, with a PGA of about 823 cm/s^2 and a PGV of 103 cm/s.

KEYWORDS: The Niigata-ken Chuetsu-oki earthquake, Empirical Green's function method, Engineering bedrock

1. INTRODUCTION

A destructive earthquake, the 2007 Niigataken Chuetsu-oki, Japan, Earthquake occurred off Middle-Niigata-ken on 16, July, 2007. During the earthquake, a severe damage occurred, with fourteen people killed, 2,354 injured and 6,494 houses collapsed or seriously damaged. Especially, a large scale nuclear power plant located near the source area was slightly damaged. For understanding the reason of the occurrence of the disaster, it is important to evaluate the strong motion in the damaged area, especially on the engineering bedrock. Among the records derived in this earthquake, the records at NIG018, a K-NET station is right in the area, but the records show the cyclic mobility phenomena obviously (as shown in figure 1), implicating that the liquefaction phenomena occurred in the area. This means that the seismic waves on the engineering bedrock cannot be estimated using the traditional methods such as SHAKE. In this study, we use the empirical Green's function method to simulate the strong motions at NIG018 on the engineering bedrock, and then calculate the surface wave for checking the results by comparing the synthetic waves with the observed ones.

2. METHODOLOGY

In this study, we use the empirical Green's function method to simulate the strong motions at NIG018 on the engineering bedrock, and then use the dynamic effective stress method to simulate the response wave on surface for checking the results by comparing the synthetic waves with the observed ones. The scheme of the empirical Green's function method adopted here is that proposed by Irikura (1986) and Irikura et al.(1997), and the dynamic effective stress analysis was performed by a computer code NANSSI/1D [Kanatani et al., 1994]. The steps of the analysis in the study are as follows: (1) construct a source model of the earthquake; (2) simulate the strong motion on the engineering bedrock based on the empirical Green's function method; (3) evaluate the seismic response on surface based on the dynamic effective stress method, including the effects of liquefaction; (4) compare the results at step 3 with the observed ones.

3. SIMULATION OF THE INCIDENT WAVE ON THE ENGINEERING BEDROCK

3.1.Source model of the earthquake

Irikura et al. (2007) has proposed a characterized source model for simulate the strong motion recorded during the 2007 Niigata Chuetsu-oki earthquake. Here, we adopt their source model in our study but with a minor modification, that is, changing the dip angle of the asperity 1 and 2 from 30 degree to 40 degree, according to the distribution of the aftershocks. Figure 2 shows the location of the source model, and Table 1 shows the main parameters of the source model. For our target is to simulate the strong motion, only the asperities, refer to as ASP1 to ASP3 hereafter, are considered. The asperities are divided into element faults based on the scaling law, as shown in Figure 2. The initial point for each asperity is shown as a star in Figure 2, and the initial time for each asperity is adjusted by comparing the onset time of the observed and simulated pulses.

3.2. The Records used for Green's function

The records used as empirical Green's functions are from two aftershocks, refer to as AFT1 and AFT2 hereafter, in the source area, the same as used by Irikura et al. (2007). The parameters of the aftershocks are shown in Table 2, and the stress drop is estimated by the corner frequency as done by Irikura et al. (2007). Here, we made some modification for all the empirical Green's functions used. Firstly we filtered the records to cut off the low-frequency component longer than 2 sec to avoid the possible noise because the magnitude of the aftershocks is relatively small. Secondly we modified the records to correct the difference of the F_{max} between the aftershocks (Fs) and the target main shock (Fm), by multiplying the records by a factor defined in Equation (3.1) proposed by Kamae et al. (1990). The F_{max} of the aftershocks, estimated by the equation (3.2) proposed by Faccioli (1986), is 13.7Hz for AFT1 and 20.9 for AFT2. The F_{max} of the main shock is set to 6 Hz. The waveform and the Fourier spectra of the modified waves at NIG018 on engineering bedrock are shown in figure 3.

$$c(f) = \frac{1+(f/F_s)^n}{1+(f/F_m)^n} \tag{3.1}$$

$$F_{max} = 7.31\times10^3 \times M_0^{-0.12} \tag{3.2}$$

In the simulation, we adopt AFT1 as an empirical Green's function for ASP1 and ASP2, and adopt AFT2 for ASP3.

3.3. Simulation of the incident wave at NIG018 in Kashiwasaki City

3.3.1 Verification of the source model

For checking the source model, we calculated the strong motion on surface at NIG005, and NIG018, the K-NET stations, NIGH01 and NIGH11, the KiK-net stations. The location of the sites is shown in Figure 2. The stations except NIG018 are selected for that they are near the source area but are enough distant to avoid obvious nonlinear effects. The synthetic seismic waves of EW component for the stations except NIG018 are shown in Figure 4. The results show that, the synthetic waves matched the observed one well, both in waveforms and in 5% damped velocity response spectra. These implicated that the source model and the aftershocks used for the empirical Green's functions is almost adequate.

Figure 5 shows the synthetic seismic waves and its velocity response on surface at NIG018. The results show that, the waveforms of acceleration for two horizontal components are overestimated in short periods, while the waveforms of vertical component and the velocity waveforms are well matched, since the vertical component and the longer component of horizontal motions are not easy to be affected by the nonlinear phenomena, including liquefaction. The above implicated that the difference between the observed and calculated waves at short periods may be caused by liquefaction phenomena, and it is difficult to evaluate the seismic wave on the engineering bedrock from the records on surface.

3.3.2 The synthetic waves on engineering bedrock at NIG018

In this section, we evaluate the seismic waves on engineering bedrock based on the empirical Green's function method. To do this, firstly the seismic waves of the aftershocks on engineering bedrock are estimated based on the Haskell's Matrix method. Here, we define the engineering bedrock as the layer with Vs of about 400 m/s. The substructure used here is assumed by Yoshida et al. (2007). The results are shown in Figure 3.

Using the seismic wave on engineering bedrock derived above, we simulated the seismic waves on engineering bedrock for the main shock based on the empirical Green's function method. Figure 6 shows the synthetic waves and showing a Peak ground acceleration and velocity are about 823 cm/s^2 and 103 cm/s. The velocity response of the results shows that at the short periods less then 0.5s synthetic waves are greater than the observed one.

3.3.3 Response analysis of the surface geology at NIG018

For checking the results derived in 3.3.2, we use the synthetic seismic wave on engineering bedrock as an incident wave to simulate the response wave on the surface based on the dynamic effective stress analysis. The calculation was performed by computer code called NANSSI/1D [Kanatani et al., 1994].

In the analysis, the substructure at the site is modeled by an elastoplastic FEM model employing a 2D plane strain element, and the bottom boundary condition is set to be a viscosity dash port for representing the continuity to the deeper understructure. The incident waves are filtered to cutoff the components longer than 2s. The parameter of substructure used in the analysis is shown in Table 3, while Vs is calculated according to N-value, and the level of underground water is assumed by Yoshida et al. (2007). The dynamic characteristics of the layers besides the assumed liquefaction layer is based on R-O model fitting Kowada-Miyamoto model, and the evaluation of the Build-up of Excess Pore Water Pressure based on the model called Nishi-model. The internal friction angle is calculated by the empirical equation proposed by Hatanaka et al.(1996) The time step in the analysis is 0.001s, and the integration method is Newmark β (β =0.25). In the analysis, we adjust the liquefaction strength of the sand layer under the underground water to reproduce the cyclic mobility phenomena, and finally the value is set to 0.18. Figure 7 shows the results in waveform and response spectra for the main motion up to 12 s. The results indicated that, for completely reproduce the time history recorded at NIG018, further more analysis should be performed, but even though there are differences between the synthetic seismic waves and the observed ones, the nonlinear effects, including the cyclic mobility phenomena are successfully reproduced, and the response velocity is well matched. These show that the amplitude of the synthetic waves on the engineering bedrock at NIG018 may be adequate.

4. CONCLUSTION

In this study, we evaluated the strong motion on engineering bedrock at a K-NET station NIG018, based on the empirical Green's function method. For verifying the results, we calculated the response wave on surface using a dynamic effective stress method, and compared the synthetic seismic waves with the observed ones. The results show that the synthetic wave matches the observed one well in response spectra, implicating that the amplitude of the synthetic wave on the engineering bedrock are adequate, with a PGA of about 823 cm/s^2 and a PGV of 103 cm/s. But for completely reproduce the time history recorded at NIG018, further more analysis should be performed.

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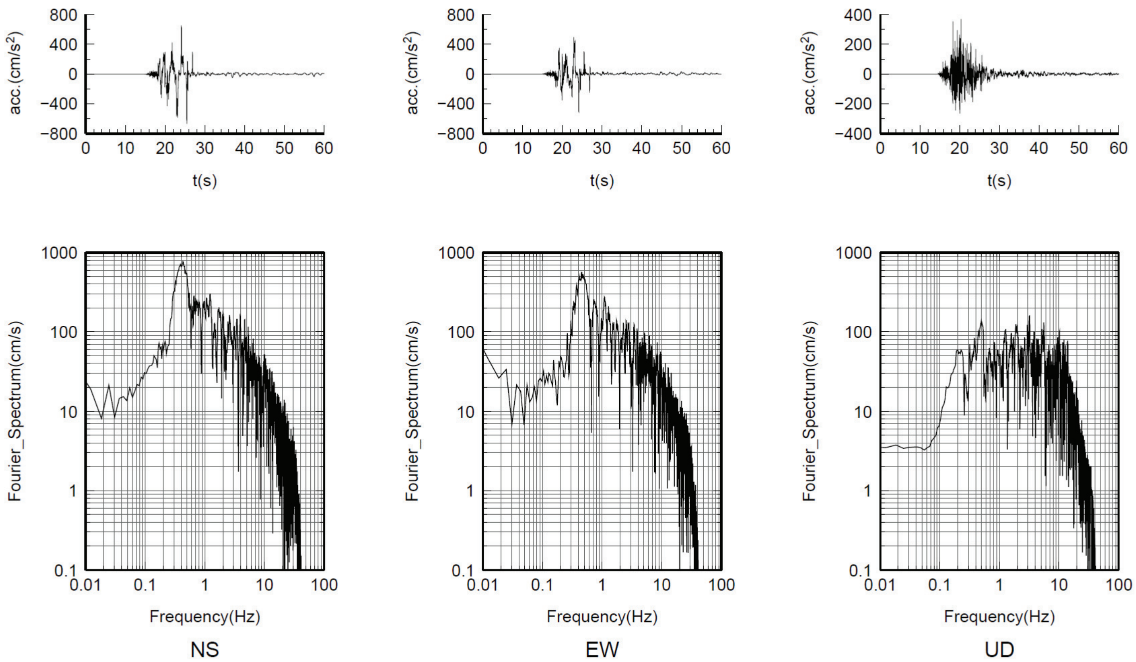

Figure 1 The waveforms and Fourier spectra of the records at NIG018

Table 1 Source parameters used in the analysis

Parameter		Asperity 1	Asperity 2	Asperity 3
Strike		37.0°	37.0°	37.0°
Dip		40.0°	40.0°	30.0°
Length	*km*	5.5	5.5	5.04
Width	*km*	5.5	5.5	5.04
M_{0a}	*Nm*	1.76E+19	2.22E+19	2.22E+19
S_a	*km²*	30.25	30.25	25.4016
D_a	*cm*	623.1	221.2	221.2
$\Delta\sigma_a$	*MPa*	23.7	23.7	19.8
Rise time	*s*	0.5	0.5	0.5
No. of subfaults		5x5	5x5	9x9
Time delay	s	0.0	5x5	9x9
V_s	*km/s*	3.4		
V_r	*km/s*	2.7		
μ	*N/m²*	3.30E+10		

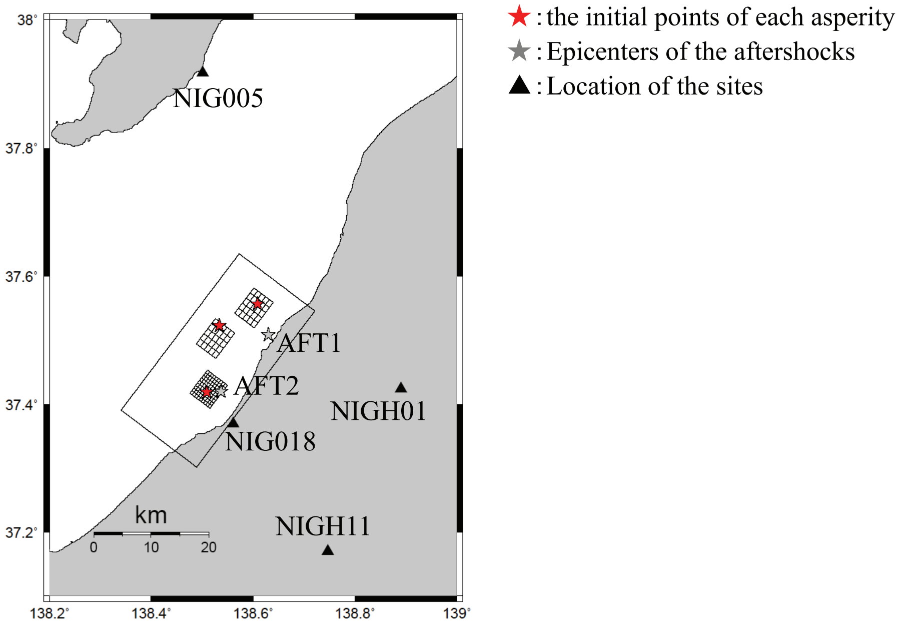

Figure 2 Location of Source model, site, and main shock and aftershocks

Table 2 Parameter of the main shock and aftershocks

	Main shck	*AFT1*	*AFT2*
Initial time	2007/7/16 10:13	2007/7/16 21:08	2007/8/4 0:16
Epicenter	138.609, 37.557	138.630, 37.509	138.537, 37.420
Focus depth	10 km	13.6 km	11.1 km
Moment	8.37E+18Nm	5.21+15Nm	1.56E+14Nm
Corner Freq.	-	1.5 Hz	4.0 Hz
Stress drop	-	3.9 MPa	2.2 MPa

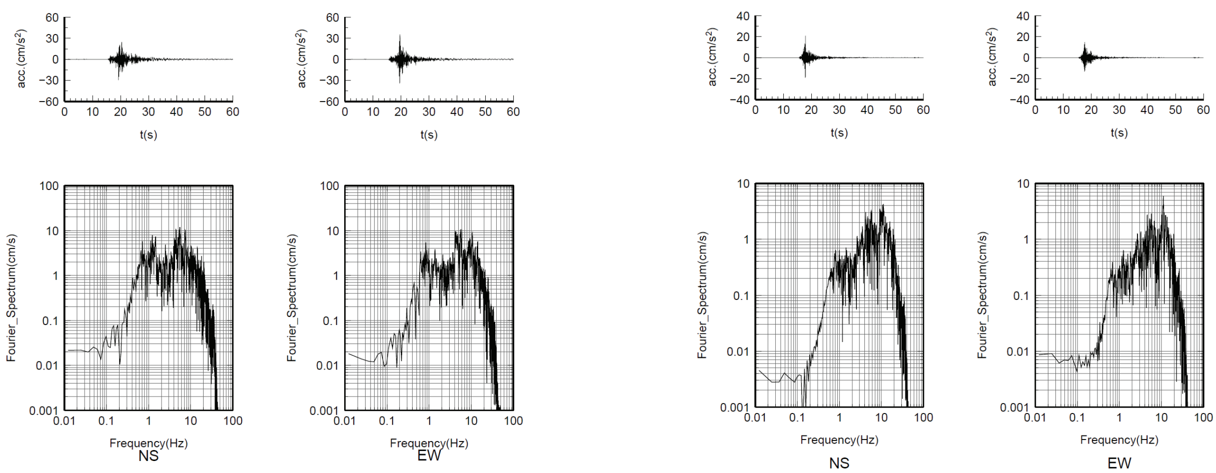

Figure 3 the Green’s functions on engineer bedrock (left: AFT1; right: AFT2)

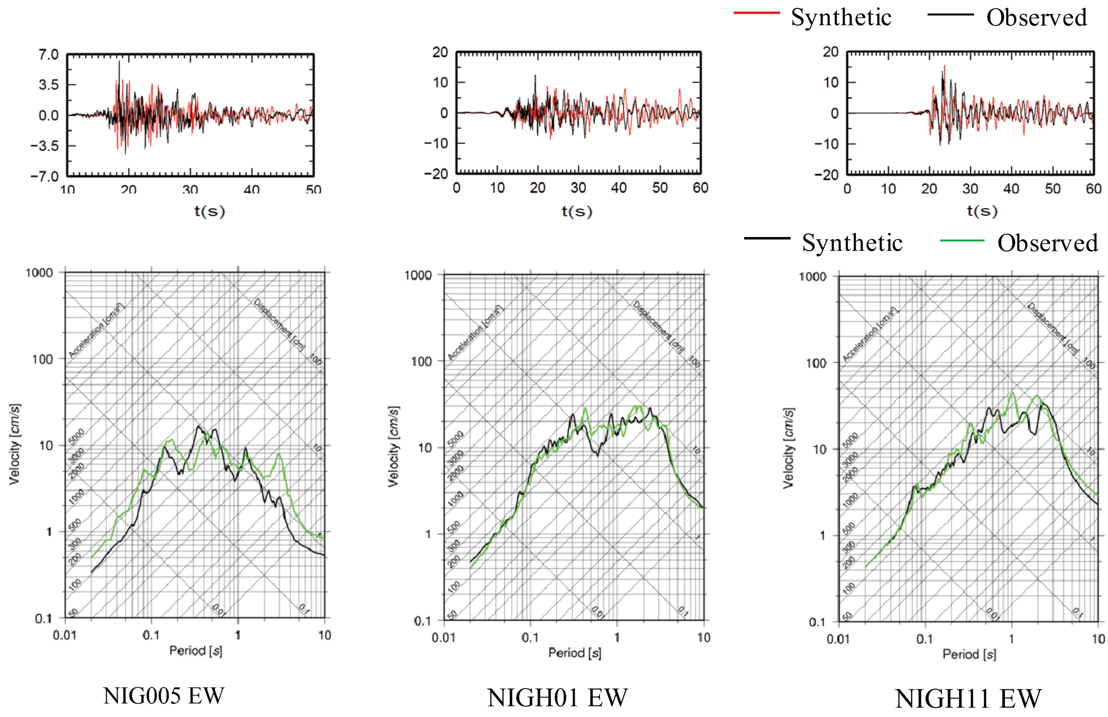

Figure 4 The synthetic waves and response spectra at NIG005, NIGH01 and NIGH11

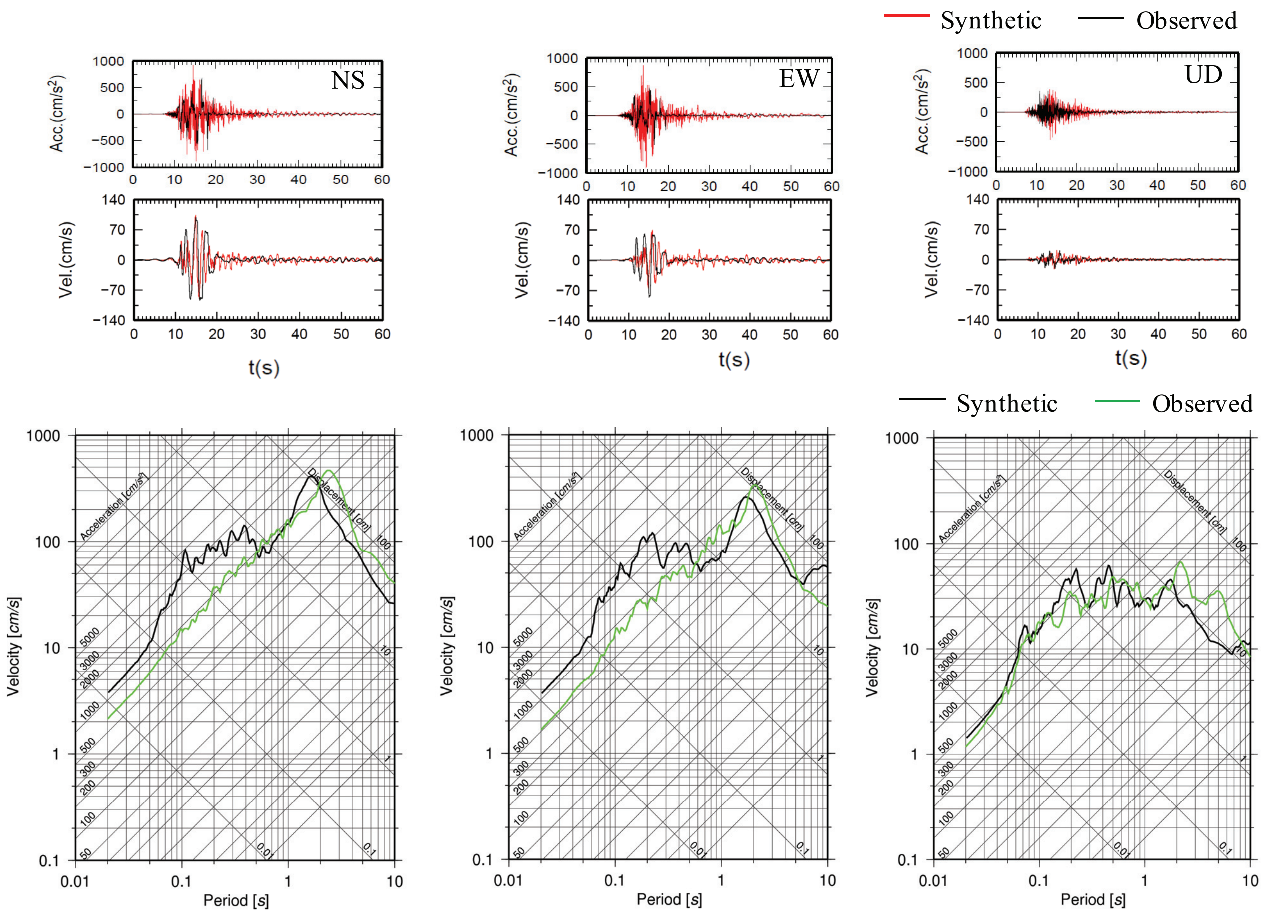

Figure 5 The synthetic results at NIG018 on surface

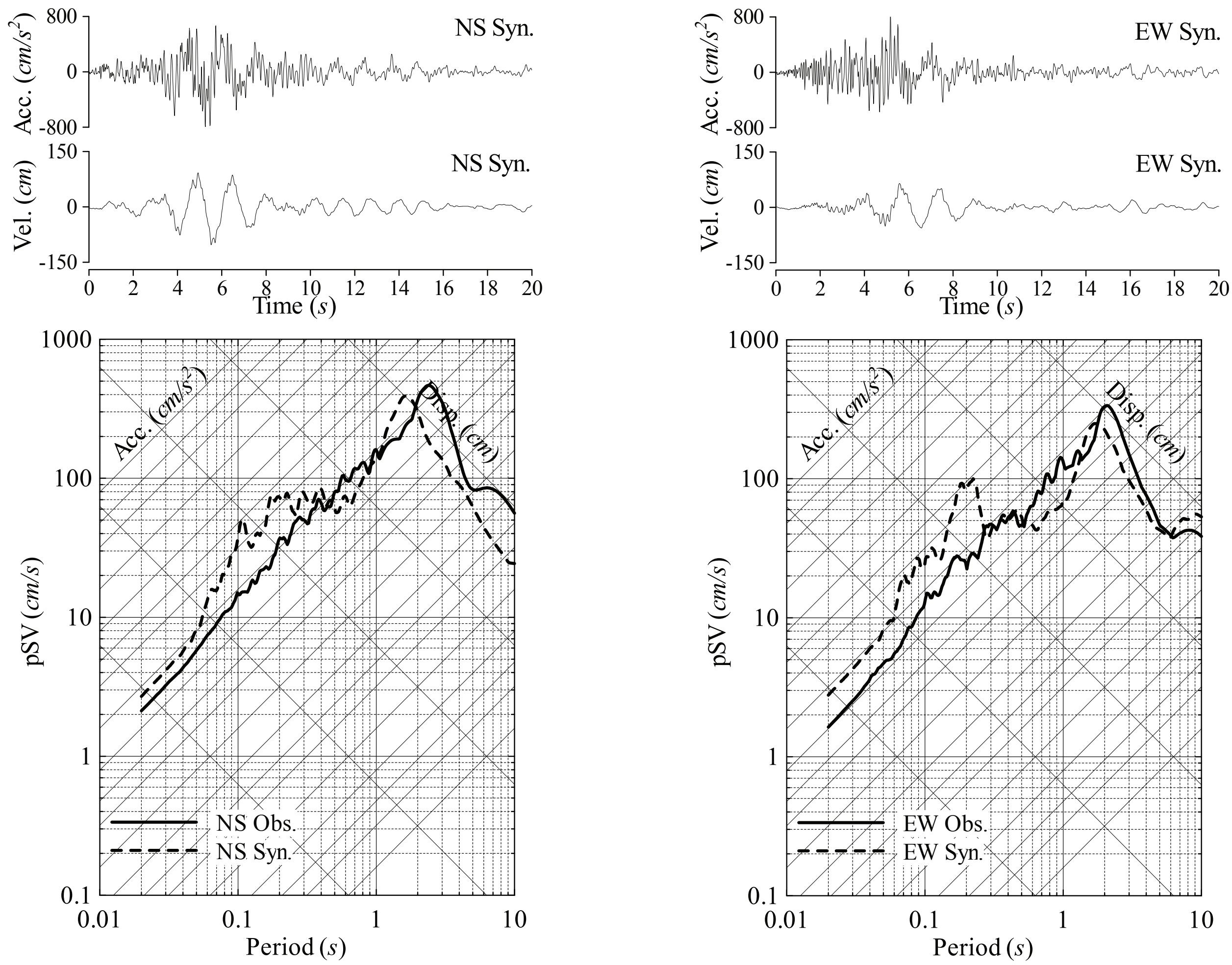

Figure 6 Synthetic waves on engineering bedrock at NIG018

Table 3 soil profile assumed at NIG018 for the dynamic effective analysis

No.	Layer	Thickness (m)	ρ (kN/m^3)	Vs (m/s)	N-value	ϕ (Degree)	Coments
1	Surface/Alluvium sand	1.10	18	84	4		
2		1.10	18	105	4		
3		1.10	18	116	20		
4	Alluvium sand (above underground	0.77	19	162	20		
5		0.77	19	168	20		
6	Alluvium sand (bebeath underground	1.09	20	174	20	43.1	liquefaction layer
7		1.09	20	181	20	42.1	
8	diluvium sand	1.14	17	274	40		
9		1.14	17	281	40		
10		1.14	17	288	40		
11		1.14	17	295	40		
12		1.14	17	301	40		
13	Diluvium clay	0.86	17	222	10		
14		0.86	17	225	10		
15		0.86	17	227	10		
16		0.86	17	230	10		
17		0.86	17	232	10		
18	Alluvium sandy clay	1.17	17	199	15		
19		1.17	17	202	15		
20		1.17	17	204	15		
21	Engineering bedrock		21	400			

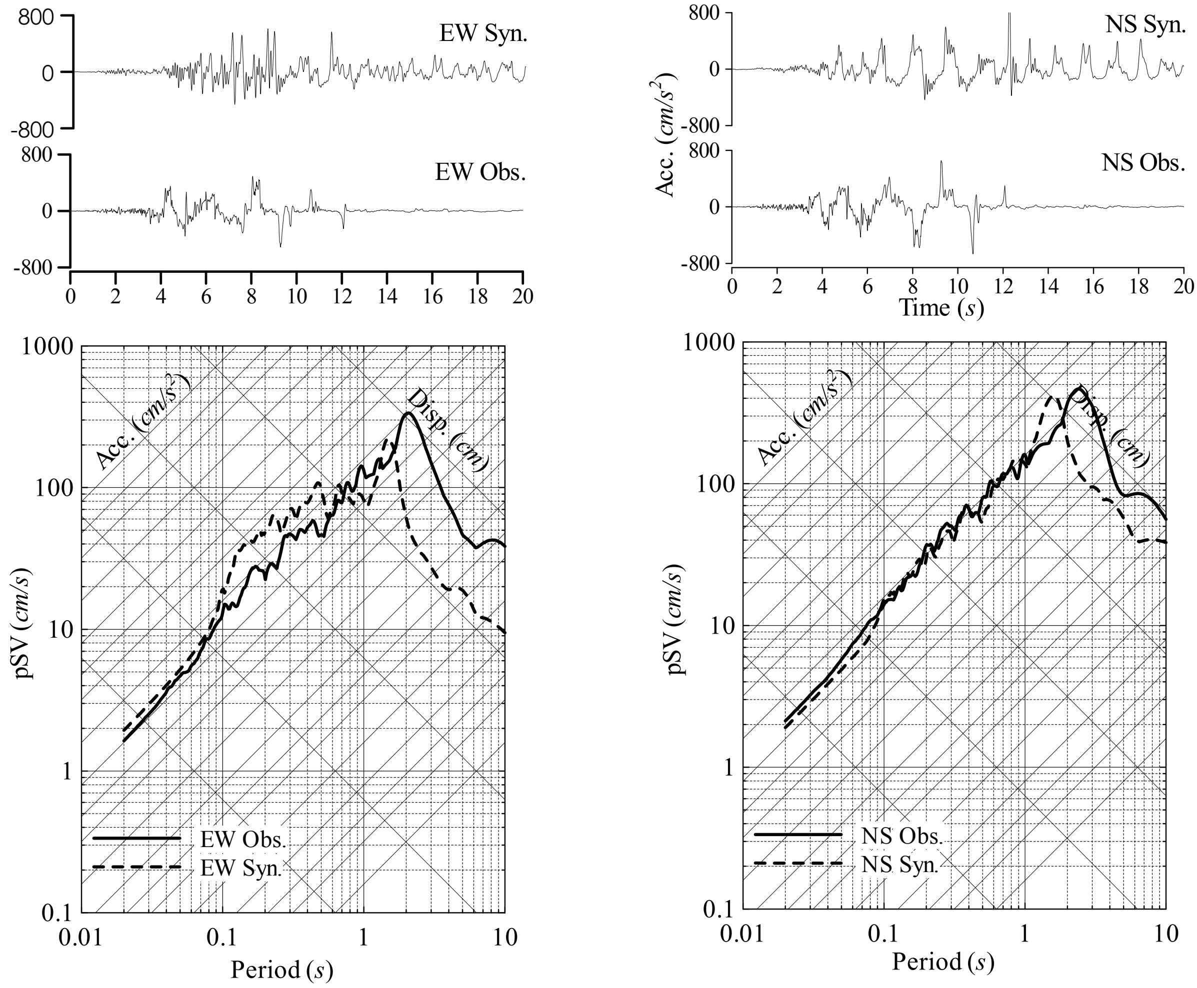

Figure 7 Comparison of the synthetic and observed in waveform and pSV

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