APPLICATION AND VERIFICATION OF THE 'RECIPE' TO STRONG-MOTION EVALUATION FOR THE 2005 WEST OFF FUKUOKA EARTHQUAKE (Mw=6.6)

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ABSTRACT :

We apply the strong-motion prediction method 'Recipe' summarized by the Headquarters for Earthquake Research Promotion of Japan to the simulation of ground motions during the 2005 west off Fukuoka earthquake. We examine four source models. For underground structure, we first construct an initial deep structure model, which is between seismic bedrock and engineering bedrock including some basins, based on borehole and geological data and revise it by using H/V spectra of observed strong-motion records. Although the simulated seismic intensities match to observed ones well, we confirm that it can be improved by introducing an intensity amplification factor. In addition, we found that the rupture velocity is an important source parameter to affect characteristics of calculated long-period waves. We also calculate waveforms on the ground for the center of Fukuoka city in which shallow velocity structure model is constructed. The result implies that we have to do continuous efforts to improve the underground structure models not only deep basin but also surface layers to predict strong-motion accurately much more.

KEYWORDS: Strong-motion prediction, underground structure model, rupture velocity, the 2005 west off Fukuoka earthquake

1. INTRODUCTION

The strong ground motion prediction plays an important role in prevention of earthquake disasters. To predict strong ground motion for future earthquakes with specified source faults, the Headquarters for Earthquake Research Promotion (HERP) of Japan summarized the procedure in accordance with the 'Recipe'. The HERP had made seismic hazard maps for 13 scenario earthquakes using the 'Recipe' and have updated by taking new insights on seismology, geology and earthquake engineering. It is very important to verify the validity of the 'Recipe' by applying to really occurred earthquakes The 2005 west off Fukuoka earthquake on March 20, 2005 (Mw=6.6), occurred near Fukuoka mega-city. This event caused severe damages in the Genkai island, a part of Fukuoka city, where locates very near the epicenter. Here we simulate strong ground motion during the 2005 west off Fukuoka earthquake by applying the 'Recipe'. Finally we suggest some revisions on the 'Recipe' form the results.

2. SOURCE MODEL

A characterized source model, which consists of one or some rectangle-shape asperities on a fault plane, is used in the strong ground motion prediction with the 'Recipe'. In this study we examine four source models. Three of them are based on the slip distributions obtained by the past source inversion analyses using the strong-motion records (cases 1-3). Another is constructed fully following the method in the 'Recipe' (case 4). The geometry of the fault plane and total seismic moment are the same in all cases. We use the area and location of the asperities and rupture velocity by referring the result of source inversion analyses. The slip and effective stress on each asperity and background (off asperity) region are calculated from empirical and/or theoretical equations summarized in the 'Recipe'. The major source parameters used in calculation of strong-motions are summarized in Table 2.1. The four source models are illustrated in Figure 1

Table 2.1 Major source parameters for calculation of strong-motions

		case 1	case 2	case 3	case 4
Fault area [km^2]		448			
Seismic moment [Nm]		1.12×10^{19}			
asperity	Area [km^2]	64	48 / 16	48	80
	Displacement [Nm]	1.60	1.79 / 1.03	1.60	1.60
	Effective stress [MPa]	20.08	20.08	26.77	16.06
background	Area [km^2]	384	384	400	368
	Displacement [m]	0.67	0.67	0.70	0.62
	Effective stress [MPa]	4.18	3.24	4.42	3.14
Rupture velocity [km/s]		3.0	2.1	2.1	2.4

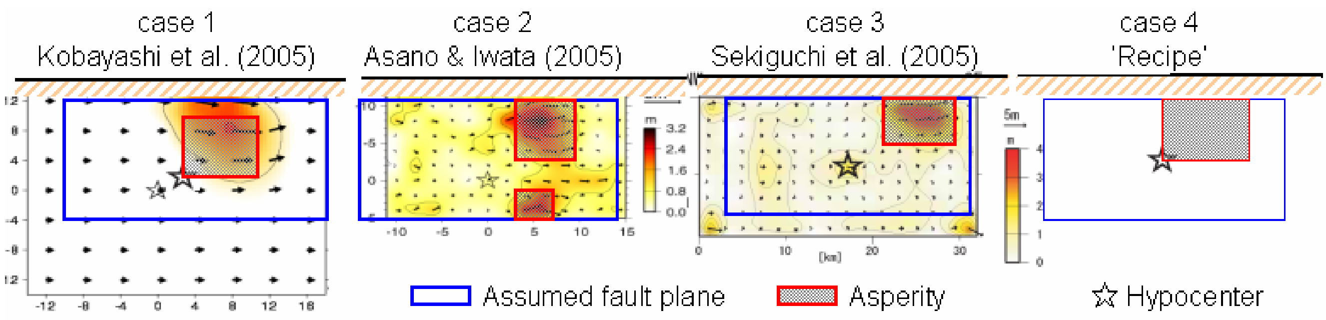

Figure 1 Four source models overdrawn on referred slip distributions by past source inversion analyses.

3. UNDERGROUND STRUCTURE MODEL

The calculation area is shown in Figure 2. This area covers strong-motion stations at which observed seismic intensity 5 upper in Japan Meteorological Agency (JMA) scale during the 2005 west off Fukuoka earthquake. We construct the deep and shallow structure model for this area. The former is the structure between the seismic bedrock (Vs~3000 m/s) and engineering bedrock (Vs~600 m/s). The later is surface structure shallower than the engineering bedrock.

3.1. Deep (Basin) structure model

First we constructed an initial deep structure model based on geophysical and geological survey data. Then we revise initial model using the spectral ratios of horizontal to vertical (H/V). The method is fitting the H/V spectra of observed coda waves to the synthetic one assuming the fundamental mode of the Rayleigh wave by trial and error (Suzuki et al., 2005). Densities are obtained from P-wave velocities by using the empirical relation by Ludwig et al. (1970). The final deep structure model is shown in Figure 2, and physical parameters for each layer are summarized in Table 3.1.

3.2. Shallow (surface) structure model

3.2.1 Model based on geomorphology

In order to predict strong-motions on the ground, the method based on geomorphologic classifications in about 1km size of mesh and empirical relation relevant to it is suggested in the 'Recipe'. Recently some researchers have updated the empirical relations. Wakamatsu and Matsuoka (2007) developed an engineering geomorphologic classification map for Kyushu region with 7.5-arc-second (about 250m) mesh. Matsuoka and Wakamatsu (2007) converted the map to distribution of average shear-wave velocity up to 30m-depth (Vs30 in m/s). Furthermore, Fujimoto and Midorikawa (2006) suggested the relation between Vs30 and amplification factor of peak ground velocity (amp_v) as follows.

Table 3.1 Physical parameters of deep (basin) structure model

Layer No.	1	2	3	4	5	6	7
Vp [m/s]	2000	2500	3000	3500	4000	5000	5500
Vs [m/s]	600	1100	1400	1700	2100	2700	3100
Density [g/cm^3]	1.90	2.15	2.25	2.30	2.40	2.50	2.60

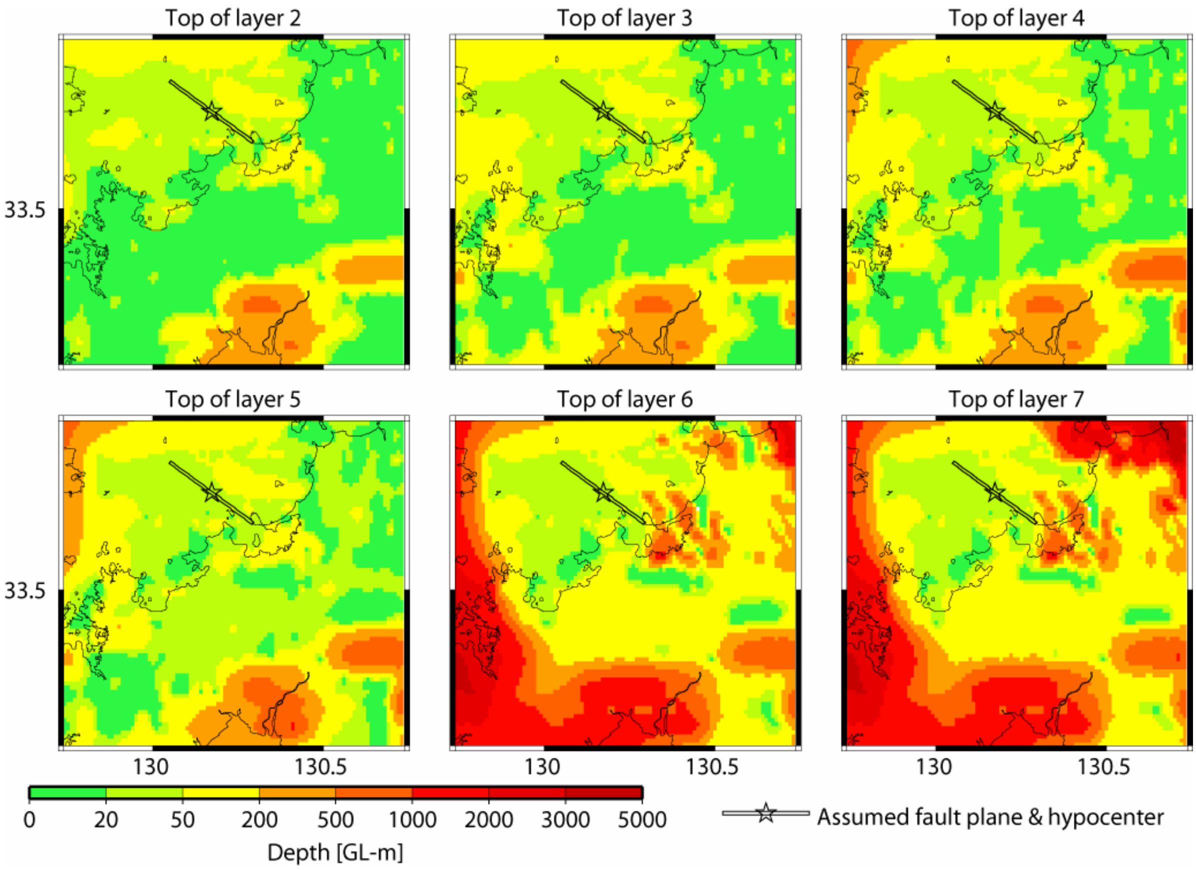

Figure 2 Deep basin structure model constructed in this study

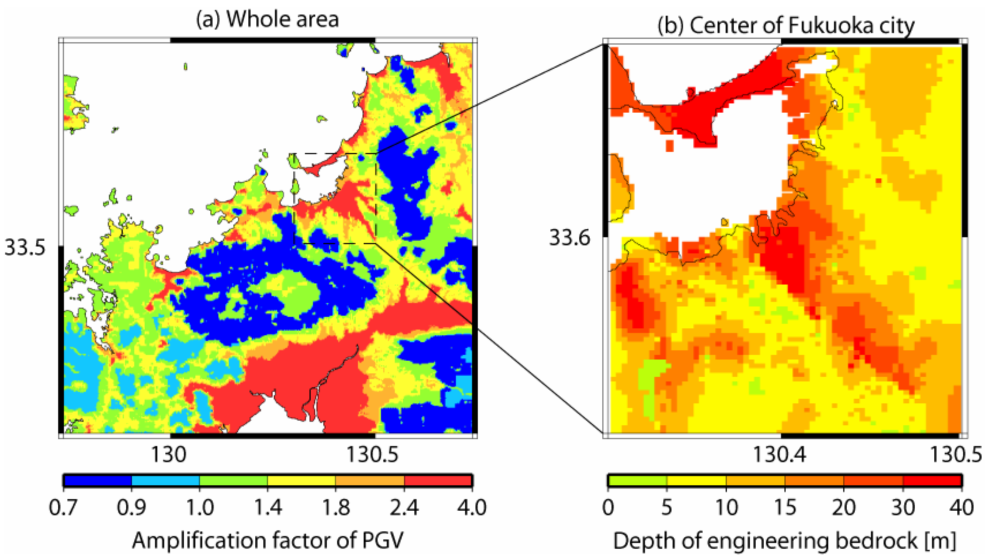

Figure 3 Shallow (surface) structure models constructed in this study

$$\log(amp_v) = 2.367 - 0.852 \cdot \log(Vs30) \quad (3.1)$$

Figure 3(a) shows the distribution of the amplification factors obtained from the geomorphologic classification map. We use these new empirical relations as the surface structure to evaluate strong-motions on the ground.

3.2.2 Velocity structure model based on bore-hole data

We construct a velocity layer model for center part of Fukuoka city in which relatively many borehole data are available. Since most borehole data are available on N-value only, we convert N-value to P- and S-wave velocities by using empirical relation by Central Disaster Prevention Council of Japan (2003). Figure 3(b) shows the depth distribution of engineering bedrock by our shallow velocity structure model.

4. CALCULATION METHOD AND RESULTS

We use a hybrid method to calculate strong-motions in broad frequency band. It is a combination of a deterministic approach for long-period waves, and a stochastic approach short-period waves. Here we use the finite difference method by Aoi and Fujiwara (1999), and the stochastic Green's function method by Dan and Sato (1998). The calculated waveforms by the two methods are synthesized in time domain after applying a pair of filters in Figure 4. In this study we calculate two horizontal components only. The peak ground velocity (PGV in cm/s) on the ground is evaluated from Eqn. (3.1) from PGV on the engineering-motion parameter for most Japanese people. In order to obtain the seismic intensity on the ground, we convert PGV on the ground to it by using an empirical relation by Fujimoto and Midorikawa (2005).

$$I = 2.002 + 2.603 \cdot \log(PGV) - 0.213 \cdot \{\log(PGV)\}^2 \quad (4.1)$$

Figure 5 shows the distribution of calculated seismic intensities and comparison with observed ones. As an overall feature, all cases can simulate observations well. However, the case 1 seems to overestimate in basin site along the strike direction of the source fault.

Figure 6 shows an example of comparison between calculated and observed waveforms on the engineering bedrock. The underestimation of short-period waves mainly caused by effects of surface structure that are not considered in the synthetic waveforms.

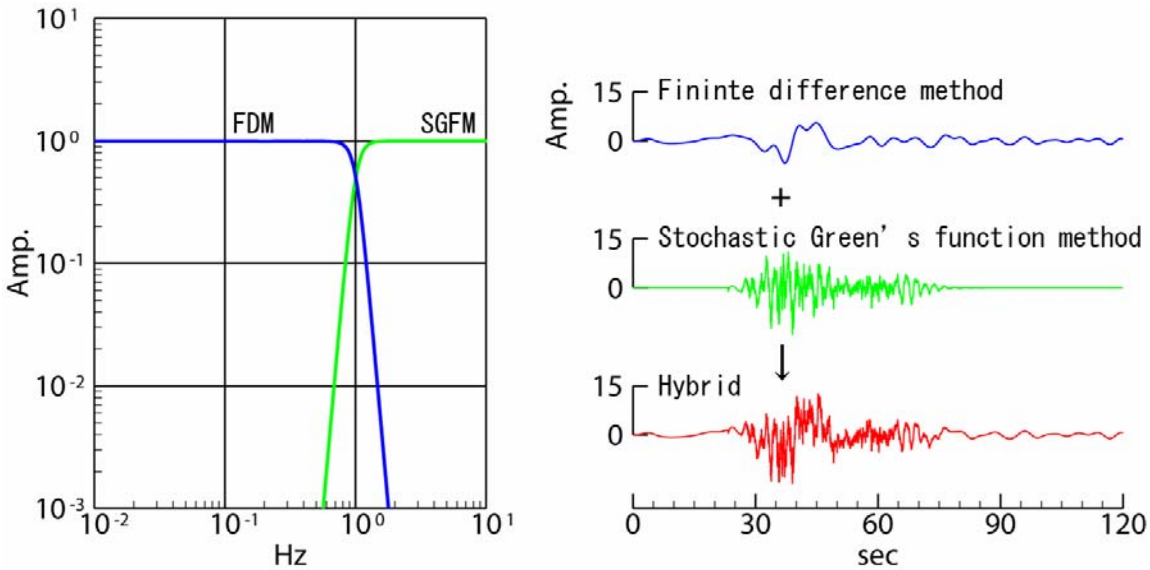

Figure 4 A pair of filter to calculate broad-band waveform on the engineering bedrock

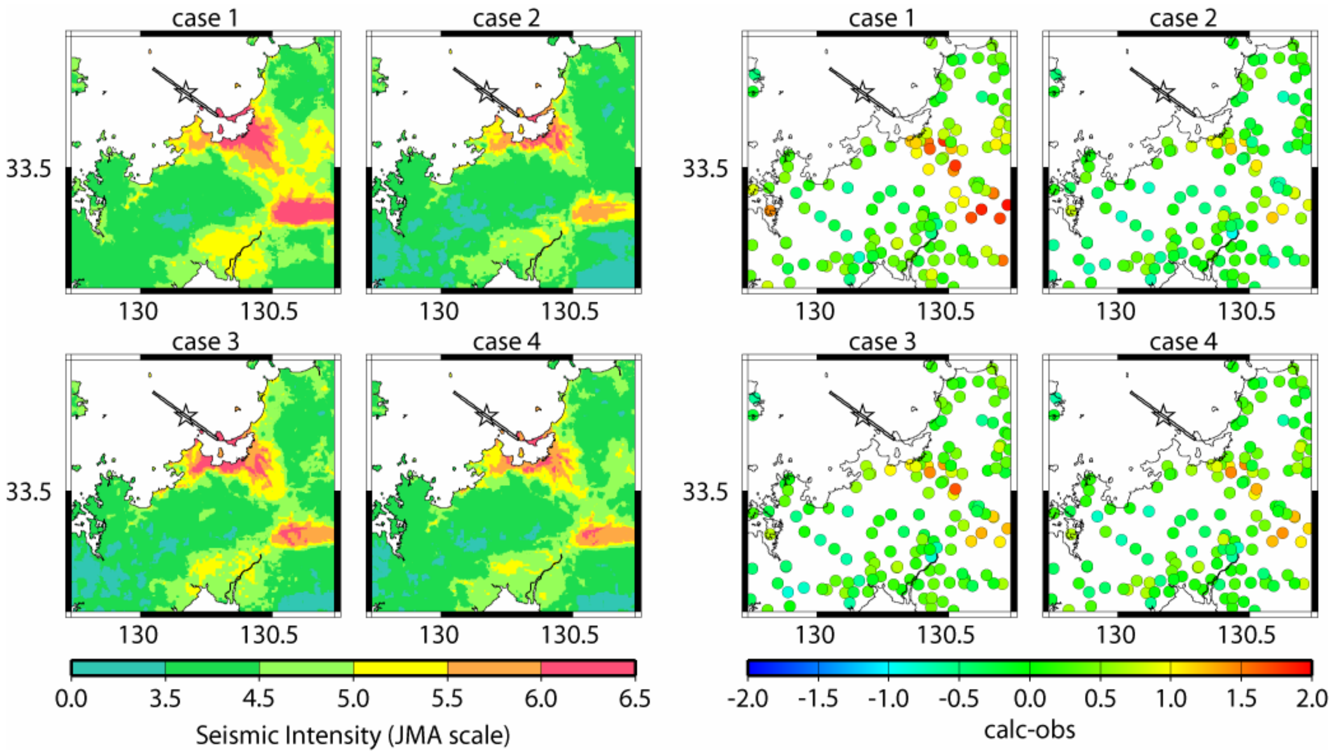

Figure 5 Calculated JMA seismic intensities (left) and comparison them with observed ones (right)

In addition, we calculate waveforms on the ground for the center area of Fukuoka city at which the shallow velocity structure model is constructed. We use a computer program 'DYNEQ' (Yoshida and Sueteomi, 1996) to apply a linear-equivalent method. The results show in the next session.

5. DISCUSSION AND CONCLUSIONS

The variation of waveforms among four cases is caused by the difference of source model. The waveforms of case 1 are relatively large while those of case 2 are small for periods longer than 1 second (Figure 6). The most different parameter between the two cases is the rupture velocity. We fond that the rupture velocity is a key factor in amplitude of long-period waves.

As mentioned above, the seismic intensities at basin sites for the strike direction of the fault plane are overestimated. However, the PGVs are almost consistent with observations. Their waveforms have a dominant period of 2-3 seconds (see FKO006 in Figure 6). As pointed out in Fujimoto and Midorikawa (2005), the correlation of the relation between PGV and seismic intensity decreases for data whose dominant period is longer than 2 seconds. To overcome this problem, we suggest an intensity amplification factor (dI) obtained by combining Eqns (3.1) and (4.1).

$$dI = 2.603 \cdot \log(amp_v) - 0.213 \cdot \{\log(amp_v)\}^2 - 0.426 \cdot \log(PGV_b) \cdot \log(amp_v) \qquad (5.1)$$

Where PGV_b is the PGV on engineering bedrock. First we calculate the seismic intensity on engineering bedrock from simulated waveforms following the definition of JMA. Then we obtain seismic intensity on the ground by adding the intensity amplification factor. As a result, the overestimations in basin are obviously improved as shown in Figure 8.

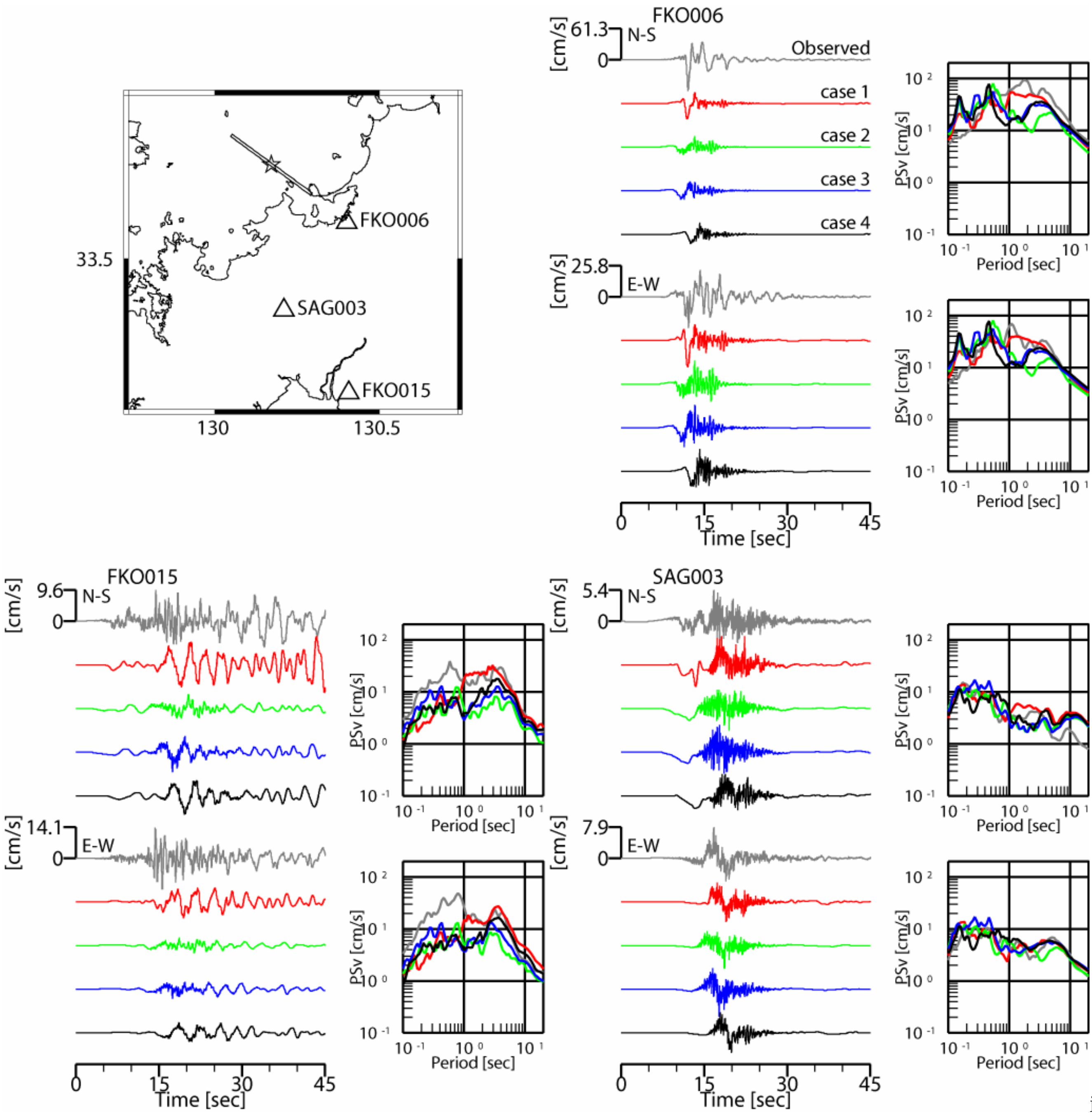

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Figure 7 Comparison of calculated waveform and its pseudo-velocity response spectrum (5% damped) on the engineering bedrock with observed ones

The fact that the result of case 4, which calculate fully following the method of the ‘Recipe’, can simulate the seismic intensity distribution during the 2005 Fukuoka earthquake shows the validity of strong-motion prediction based on the ‘Recipe’ (Figure 5). However, the match between observed and synthesized waveforms not enough, especially at sites located on the deep sedimentary basin. Further improvements for underground structure models not only deep basin but also subsurface structures are required to predict more accurate strong-motion waveforms.

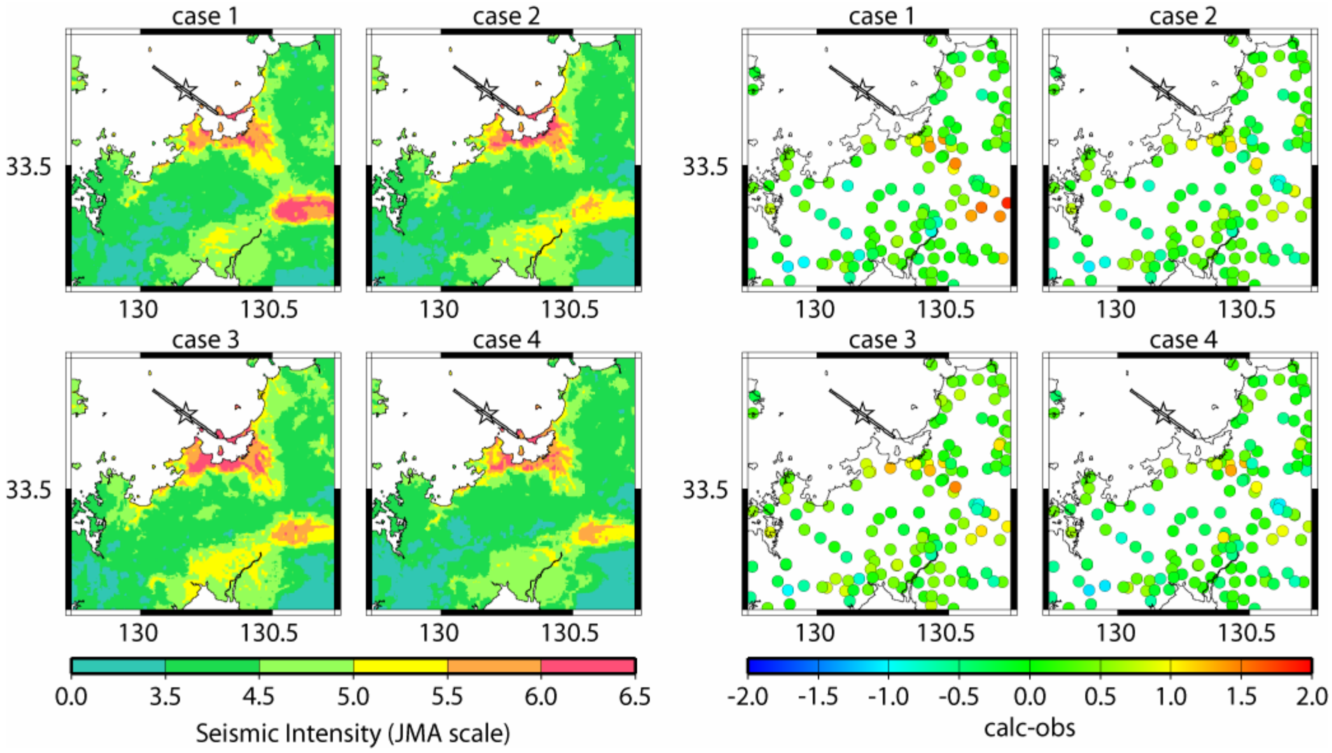

Figure 7 Seismic intensities obtained by applying Eqn. (5.1) and comparison them with observed ones

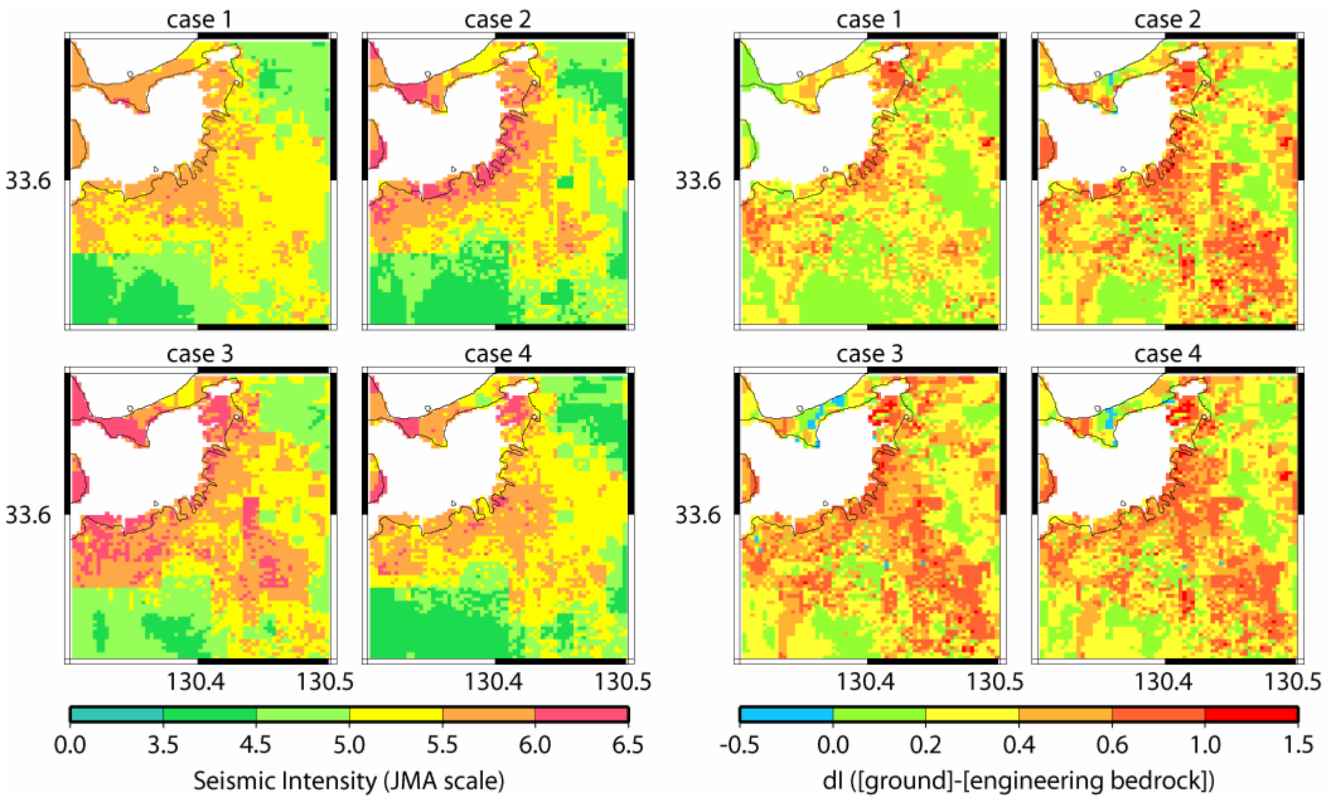

Figure 8 Seismic intensities obtained by applying equivalent-linear method and their amplification from the engineering bedrock

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