EARTHQUAKE GROUND MOTION SIMULATION BASED ON FINITE ELEMENT METHOD IN OJIYA CITY, JAPAN

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ABSTRACT:

Strong ground motion simulation based on 2-dimensional finite element method considering topographic effects, local site effects of sedimentary layer and soil-structure interaction has been presented in this paper. The simulation has been carried out for the 2004 Mid Niigata Prefecture Earthquake (M_{JMA} 6.8), in Ojiya city, Japan. The Ojiya General Hospital is located in Ojiya city, the vicinity of the mainshock, which is one of damaged buildings. Input ground motion to this building is required to explain the damages. Strong ground motion records were observed for the mainshock and its aftershocks at a neighboring base-isolation building, Suisen-no-ie. Suisen-no-ie, however, is located at the foot of a hill, while the Ojiya General Hospital is located at the edge of a hilltop. It is likely that input earthquake motions were different between two buildings. Therefore, we have performed microtremor measurements to investigate the structure of surface soft layers. A 2D-FEM model has been constructed, explaining both the peak frequencies of H/V ratios of microtremor observation and Fourier spectral ratios for aftershocks between the Ojiya General Hospital and Suisen-no-ie. Then, we simulated the earthquake ground motion during the mainshock and clarified the topographic effects on both buildings, the different local site effects of surface soft layer and soil-structure interaction. Finally, the structural damages of the buildings have been described from differences in input ground motions.

KEYWORDS: The 2004 Mid Niigata Prefecture Earthquake, Ojiya City, Finite Element Method, Topography Effects, Surface Soft Layer

1. INTRODUCTION

The Mid Niigata Prefecture Earthquake with JMA magnitude 6.8 occurred on October 23, 2004, at Niigata prefecture in central Japan. The JMA intensity 6 upper were observed and several buildings were severely damaged in Ojiya city, which is in the vicinity of the mainshock. The Ojiya General Hospital is one of damaged buildings located in downtown Ojiya city. The hospital has adjacent 5 buildings, which have different floor area, stories and structural type, being connected by expansion joints. Shear failure of non-structural walls and cracks in structural walls were observed (Iiba *et al*., 2007). Input ground motion to this building is required to explain these damages. Strong ground motion records were observed for the mainshock and its aftershocks at a neighboring base-isolation building, Suisen-no-ie (Welfare Nursing Care Center). The peak acceleration observed during the main shock was 740cm/s^2. Suisen-no-ie, however, is located at the foot of a hill, while the Ojiya General Hospital is located at the edge of a hilltop. It is likely that input ground motions were different between two buildings.
The strong ground motion of the mainshock at the Ojiya General Hospital has been evaluated using the records at Suisen-no-ie in this paper. For that purpose, it is necessary to clarify the topographic effects on both buildings, the different local site effects of sedimentary layer and soil-structure interaction. To investigate the structure of sedimentary layer, we have performed microtremor measurements around these buildings. Aftershock observation at two buildings has been also conducted. A soil structure model for the 2D FEM has been constructed based on the observed data to simulate the earthquake ground motion during the mainshock. Finally, the structural damages of the buildings have been described from differences in input ground motions.

2. MODEL DESCRIPTION

2.1 Strong motion and microtremor measurements

Fig. 1 shows the epicenter of the mainshock (red star) and the location of Ojiya city (blue circle). The Ojiya General Hospital is located in downtown Ojiya city, the epicentral distance of about 6 km. Fig. 2 shows the location of the buildings. Shaded area indicates the hill area whose altitude is higher than 55 meters above sea level. The Ojiya General Hospital is located on the hill and its altitude is 62.5 meters. Contrarily, the altitude of Suisen-no-ie, which is located on the foot of the hill, is 50 meters. Pluses in Fig. 2 indicate the location of boring explorations and PS logging. It can be seen in Fig. 2 that many boring data have been obtained. To estimate site amplification in this area, we performed microtremor measurements. Triangles and rectangles in Fig. 2 indicate the stations of triangle array for microtremor measurements conducted by Fukumoto *et al*. (2007) and the microtremor measurement points for H/V spectral ratio by Yoshimura *et al*. (2007), respectively.
Fig. 3 shows soil profiles at stations of microtremor array measurements near the Ojiya General Hospital (No.5), Suisen-no-ie (No.3) and station No.1, which were evaluated by an inversion analysis of Rayleigh wave dispersion curve by Fukumoto *et al*. (2007). Vertical axes of Fig. 3 indicate altitude. Notable differences between stations can be seen at the soil profiles higher than 10[m]. It is likely that the differences influence the characteristics of strong ground motion.

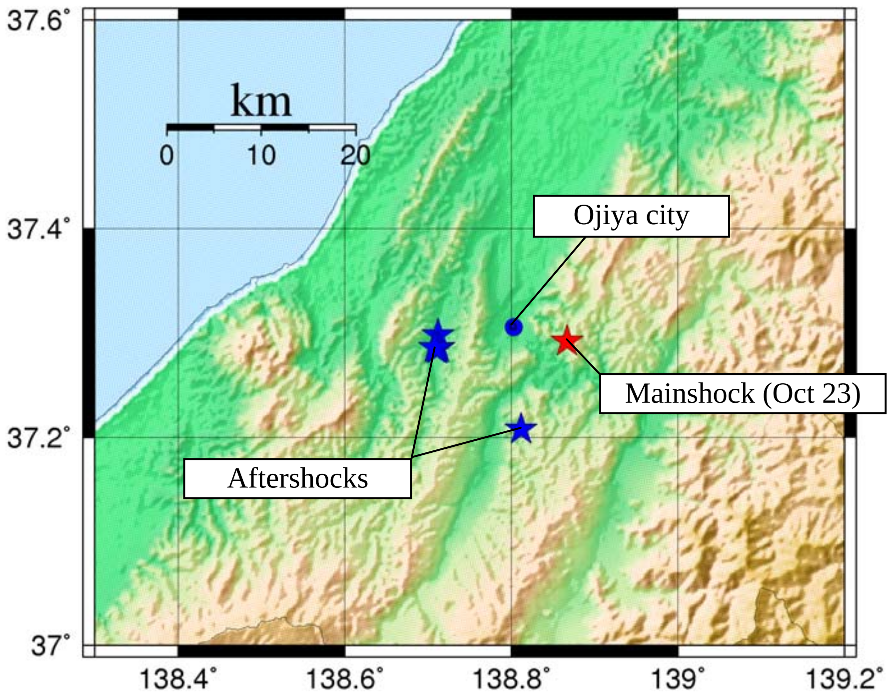


Fig. 1 Epicenters of the mainshock and aftershocks, location of Ojiya city

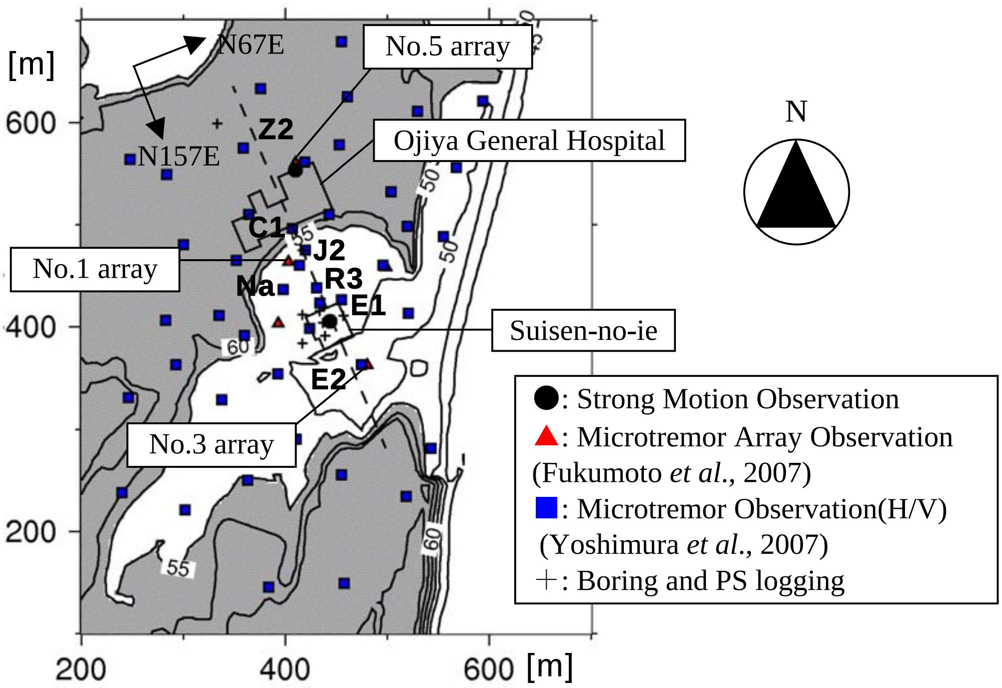


Fig. 2 Altitude (m), building layout, location of strong motion observation and microtremor measurements

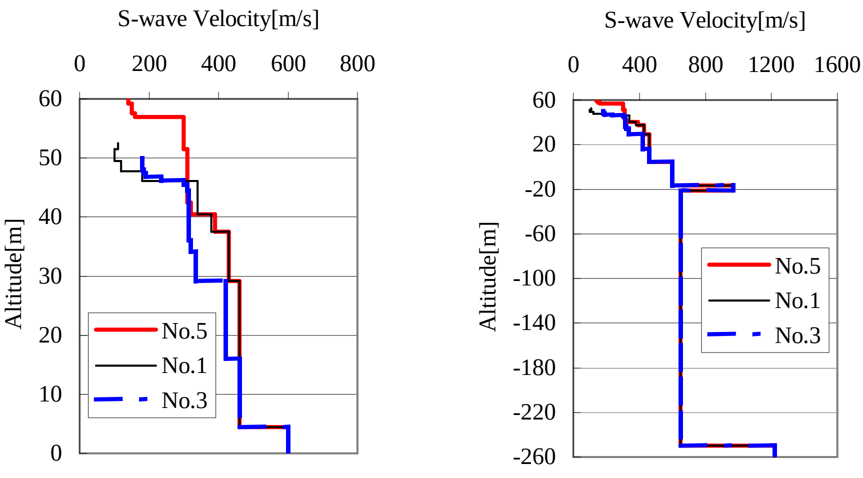


Fig. 3 Soil profiles at the stations of microtremor array measurements (Fukumoto, 2007)

The strong motion during the mainshock has been recorded only at Suisen-no-ie. To understand the characteristics of input earthquake motion to the Ojiya General Hospital, we conducted aftershock observation on foundation of both buildings. Black circles in Fig. 2 indicate the location of seismographs. N67E and N157E were observed. Table 1 summarizes observed peak ground accelerations (PGA), which is larger horizontal component, for five aftershocks (see. Fig. 1). PGA ratios from Suisen-no-ie to the Ojiya General Hospital range from 0.64 to 0.87 for 5 aftershocks. It is clear that PGA at the Ojiya General Hospital is slightly smaller than that at Suisen-no-ie.

Table 1 Observed Aftershocks

Date and Time	Epicentral Distance [km]	JMA Magnitude	Hospital PGA [cm/s2]	Suisen-no-ie PGA [cm/s2]	PGA Ratio Ojiya General Hospital / Suisen-no-ie
2005/8/20 22:11	10.9	3.5	10.4	12.0	0.87
2005/8/21 11:29	8.1	5.0	53.7	83.1	0.65
2005/8/21 16:43	8.3	3.8	5.9	7.8	0.76
2005/8/22 02:27	8.5	3.8	9.2	14.3	0.64
2005/8/22 14:55	8.7	3.6	4.5	5.9	0.76
				mean value	0.74

2.2 2D-FEM Model

2D-FEM model (Fig. 4) has been constructed along the dashed line (N157E) in Fig. 2 based on aftershock records, microtremor observation data, boring data and PS logging. Table 2 shows the soil parameters of the model. Numbers in Fig.2 correspond to material numbers in Table 2 (for instance, S-wave velocity of (3) in Fig. 4 is 360[m/s]). Vertical axis of Fig. 4 indicates altitude. Here, we have modeled the soil structure above altitude of –250[m]. Altitude of –250[m] corresponds to the depth of -310m at which bedrock motions of the mainshock evaluated by Fukumoto *et al*. (2006). Material parameters have been determined based on Fukumoto *et al*. (2006) and PS logging. S-wave velocity of the bedrock layer was assumed 1,220[m/s] (Material No.14 in Table 2) based on Fukumoto *et al*. (2006). Furthermore, foundations of the Ojiya General Hospital and Suisen-no-ie and retaining wall have been modeled by concrete (see material No.15 in Table 2) (Yoshimura *et al*. 2004). Viscous boundaries were installed at both sides of the model and energy transmitting boundary was installed at the bottom of the model.

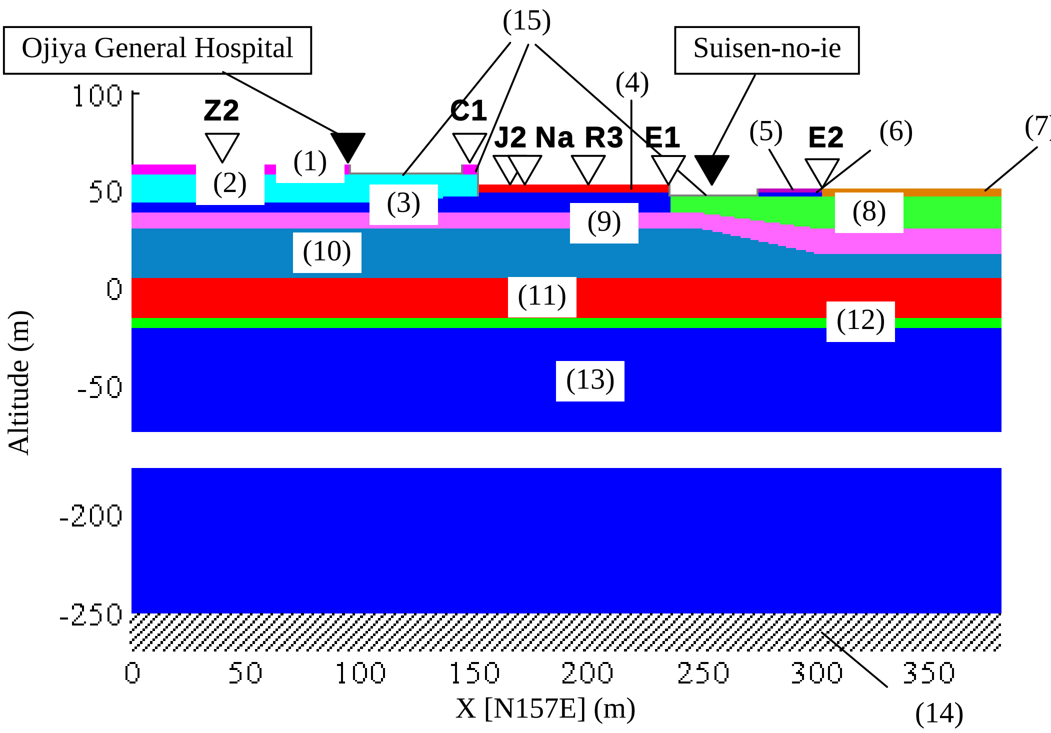


Fig. 4 2D-FEM model for simulation

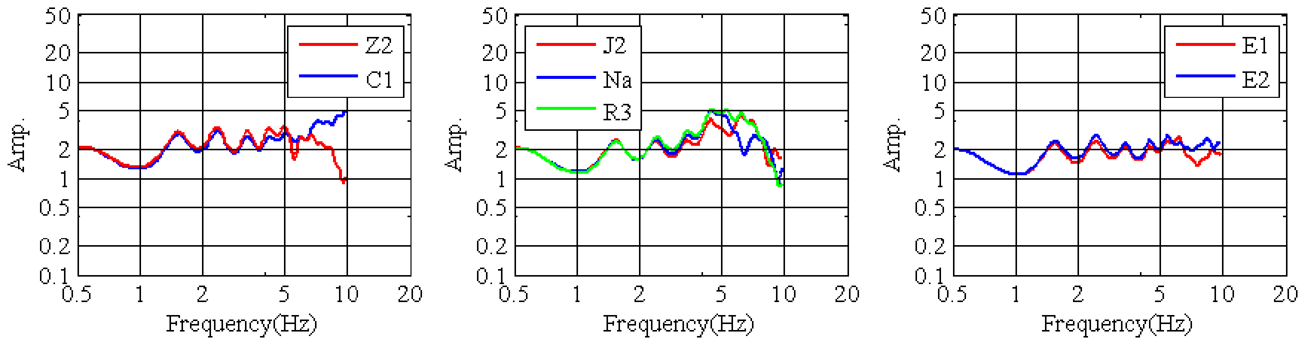
Table 2 Soil parameters

Material No.	type	Vs (m/s)	Vp (m/s)	ρ (g/cm3)	h
1	clay	144	500	1.65	0.052
2	gravel	300	700	1.9	0.025
3	sandstone	360	1350	1.9	0.021
4	clay	110	500	1.65	0.068
5	sandy silt	140	530	1.9	0.054
6	gravel	180	1300	1.9	0.042
7	gravel	191	1300	1.8	0.039
8	mudstone	320	1300	1.9	0.023
9	mudstone	430	1670	1.8	0.017
10	mudstone	460	1670	1.85	0.016
11	mudstone	600	1670	1.8	0.013
12	mudstone	970	1960	2.1	0.008
13	mudstone	650	1740	1.9	0.012
14	mudstone	1220	2640	2.1	0.006
15	concrete	4200	6640	2.4	0.002

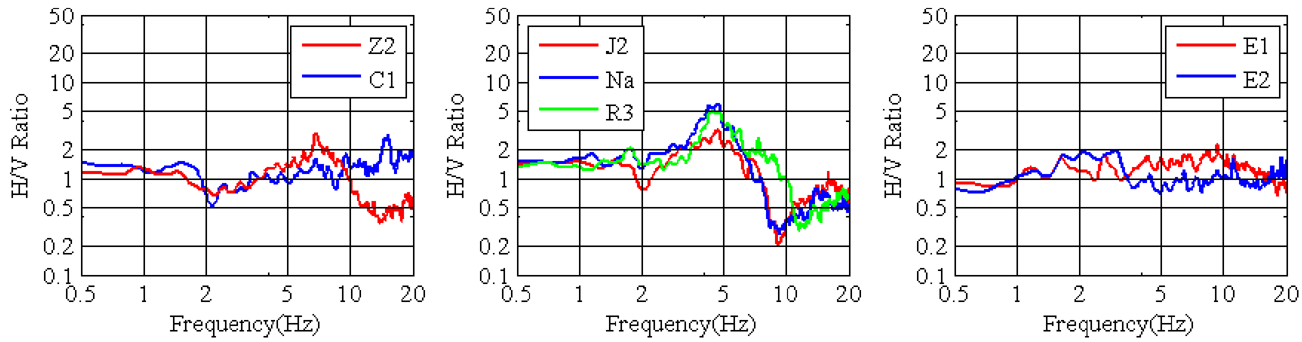
2.3 Validation of FEM model by linear FE analysis

Simulation of Fourier spectral ratios between the Ojiya General Hospital and Suisen-no-ie has been performed to confirm validity of the 2D-FEM model. The simulation has been limited to frequencies below about 10Hz. Surface ground motion for vertically incident SV wave to the bottom of the model was calculated. Then, site amplification factors are obtained from the ratio between the calculated surface motion and the incident wave. We used white noise as the incident wave. Fig. 5(a) shows the site amplification factors by the 2D-FEM model at the stations of the microtremor measurements by Yoshimura *et al*. (2007). Fig. 5(b) shows H/V spectra of microtremor records (Yoshimura *et al*., 2007). Triangles in Fig. 4 show the location of the microtremor measurements. Here, the comparison is based on the premises that peak frequencies of calculated S-wave site amplification factors correspond to those of H/V ratio of microtremor (Nakamura and Ueno, 1986). It is found from Fig. 5 that there is spatial variation of the underground soil structure in this area. J2, Na and R3 are located at the foot of the hill between the Ojiya General Hospital and Suisen-no-ie. A thick sedimentary layer on surface (Material No. 4) generates a peak at periods from 4 to 5 Hz at these stations. On the other hand, we cannot see clear peaks at E1, E2 and C1. The simulated site amplifications explain these characteristics of H/V ratios of microtremor observation.

Fig. 6 shows Fourier spectral ratio obtained from 2D-FEM simulation results (Red bold line) between the Ojiya General Hospital and Suisen-no-ie. Blue thin dotted line shows site amplification factor calculated based on 1-dimensional analysis. Black lines indicate observed Fourier spectral ratio for 5 aftershocks, which are smoothed using Parzen window with a bandwidth of 0.5 Hz. The values of Fourier spectral ratios range from 0.5 to 2. The observed spectral ratios have peaks at around 0.25 s. The spectral ratios increase as the period increases from 0.15 s and 0.3 s, exceeding 1.0 at longer period than 0.3 s. It is found from Fig. 6 that these characteristics of the observed Fourier spectral ratio are explained by the simulation result of 2D-FEM model.



(a) Site amplification factors by 2D FEM



(b) Observed H/V ratios (Yoshimura *et al*., 2007)

Fig. 5 Comparison between site amplification factors and H/V ratios at the stations of microtremor measurements

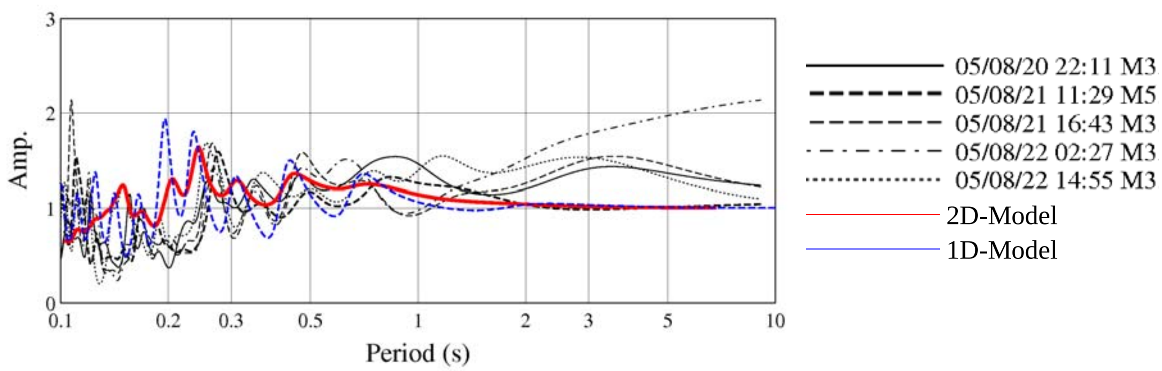


Fig. 6 Simulated and observed Fourier spectral ratios between at the Ojiya General Hospital and at Suisen-no-ie

3. EQUIVALENT LINEAR FE ANALYSIS FOR MAINSHOCK

Strong motion simulation for the mainshock using 2D-FEM model has been performed to evaluate the differences in input earthquake motions to the two buildings. Bedrock motion, which gets rid of the influence of the surface soft layer, was obtained by Fukumoto *et al*. (2006) using 1D model. We use it as an initial model for incident SV wave. However, site amplification factors based on 1D model and 2D model are different as shown in Fig. 6. Therefore, we have modified the incident wave so that the motion obtained from 2D-model at Suisen-no-ie corresponds to the observed records. Soil nonlinearity models obtained by Fukumoto *et al*. (2006) are used for an equivalent linear model. Fig. 7 shows response acceleration time history and acceleration response spectra with a damping of 5% in N157E direction at two buildings. Dashed line in Fig. 7 indicates the response spectrum of input outcrop motion. A 0.1Hz lowpass filter is applied to the results.

It is found from Fig. 7 that the characteristics of input earthquake motions to the neighboring two buildings are different. The response spectrum at period from 0.3 s to 2.0 s at the Ojiya General Hospital is larger than that at Suisen-no-ie. On the other hand, the response spectrum at period less than 0.3 s at the Ojiya General Hospital is smaller than that at Suisen-no-ie. The period of 0.3 s at which the spectral amplitude at Ojiya General Hospital become larger than that at Suisen-no-ie seems to be longer comparing the spectral ratios in Fig. 6. It is likely because of the different effects of the sedimentary layer under the buildings with a thickness of about 20 m, as well as the topographic effects. Furthermore, the response spectrum at period from 0.1 s to 0.15 s at the Ojiya General Hospital is smaller than that of bedrock motion. It is clear that the nonlinearity of gravel layer (Material No. 2) under the hospital influences the responses. The fundamental natural period of the Ojiya General Hospital ranges from 0.2 s to 0.3 s. It is required to take the difference of input earthquake motion into account when examining the response and damage of the Ojiya General Hospital.

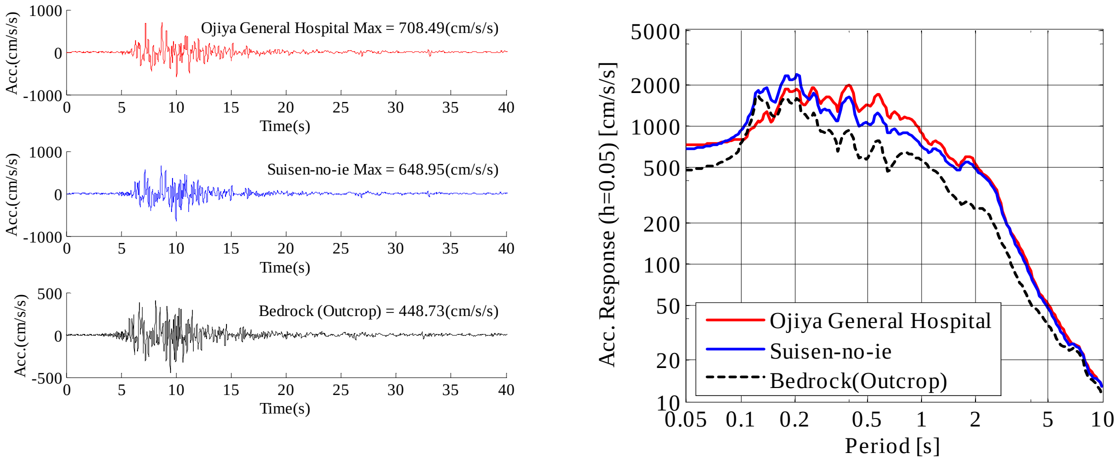


Fig. 7 Simulated acceleration waveforms and response spectra in N157E direction for the 2004 earthquake at the Ojiya General Hospital and Suisen-no-ie

4. CONCLUSION

We have performed strong ground motion simulation based on 2-dimensional finite element method during the 2004 Mid Niigata Prefecture Earthquake, in Ojiya city, considering topographic effects, different local site effects of surface soft layer and soil-structure interaction. 2D-FEM model in Ojiya city has been constructed based on aftershock records, microtremor observation data, boring data and PS logging. It is found from the simulation results that the characteristics of input earthquake motion to the neighboring two buildings are significantly different. It is possible to explain the structural damage of the Ojiya General Hospital by considering the differences in input earthquake motions.

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