Characteristics of seismic motions and pore pressure response in the filled slopes

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Abstract

Landslides in the filled slopes due to strong seismic motion frequently caused damages to the constructions in Japan (e.g. Kamai, 2011a). Seismic observations are urgent in order to understand the generation mechanism of large shaking. Seismic observations are conducted in the filled slope in Tokyo, Japan (Kamai, 2011b). A three-component seismometer and a barometer are settled on the ground in the filled slope, while pore pressure is measured in the borehole at the depth of 4.8 m (ground water level is at ~ 2 m depth). Another seismometer is settled on the sediment ground, 1 km apart from the filled slope site, for comparison. The seismograms are continuously recorded with the sampling interval 5 ms, while barometric and pore pressures are recorded every 10 ms. We analyzed waveform records of 24 earthquakes whose magnitudes and epicentral distances ranged 3.5-6.5 and 20-300 km, respectively. The peak ground acceleration (PGA) was ranging 3-170 gal, which was a few times larger in the filled slope than that on the ground for all the analyzed earthquakes. Vertical component of S-waves was so much amplified that it almost equaled to those in horizontal components. From spectral analysis, this is found to be due to the amplification of the waveform components of 5-8 Hz and around 20 Hz. Transient change in pore pressure was also observed according to the arrival of the seismic waves. The level of pore pressure increased when large acceleration due to S-wave's arrival was observed, which indicated that large shear waves made the soil plastic. Then, the level of pore pressure gradually decreased but never returned to the original level. It is indicated that the soil condition may be changed into another state due to the strong seismic motion.

Keywords: filled slope, strong motion, pore pressure

1. Introduction

Japan experiences lots of huge earthquakes. Landslides in the filled slopes due to strong seismic motions were often reported. For example, Midorigaoka district, Sendai city suffered from huge damages on houses and residential areas due to 2011 off Pacific Tohoku earthquake (Kamai, 2011a; 2014). It is reported that Nankai earthquake or Kanto earthquake is going to take place in the near future with high possibility (The headquarters for earthquake research promotion, 2013; 2014). It is urgent to elucidate the generation mechanism of landslides in the filled slopes.

In order to estimate the stability of the slope during earthquake shaking, it is important to know the role of the ground water as well as the characteristics of the seismic strong motions. Kamai (2011b) conducted multi observations of ground motions and pore pressure in the filled slope in Meguro ward, Tokyo prefecture. This slope was filled in the valley which was made by dissecting the loam plateau. We presented here characteristics of strong motions and pore pressure behaviors in the filled slopes through such observations.

2. Data

We have observation sites in the Fusuma-cho Park, which is located in the filled slope in Meguro ward, Tokyo prefecture. High sensitivity seismometers (KVS300) with the natural frequency 2 Hz as well as a barometer were installed on the ground. Pore pressure is also measured at depth of 4.8 m, which almost corresponds to the bottom of the filled slope. The ground water level is 2-3 m in depth, which means that approximately half of the filled slope is saturated. The drilling log in the Fusuma-cho Park is shown in Figure 1. For comparison, we have another seismometer on a sediment ground at Ryugenji Temple, which is located about 1 km away from Fusuma-cho Park. Ryugenji Temple is located

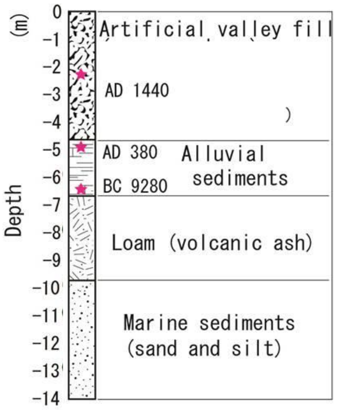

Figure 1: Vertical geological profile in the filled slope at Fusuma-cho Park.

on the loam plateau.

Seismic motions were recorded every 5 ms while barometer and pore pressure were every 10 ms. The resolutions were as high as 24 bit. The data were acquired from October, 2013.

The locations of observation sites and epicenters used in this analysis were shown on the map in Figure 2. The depth and magnitudes were ranging from 10 km to 400 km, and from 3.5 to 6.5, respectively.

3. Seismic waveform and pore pressure records for the event on Nov. 29, 2013.

In Figure 3, we show seismic waveform records at Fusuma-cho Park and Ryugenji Temple, together with the pore pressure records at Fusuma-cho Park, accompanied with the event located 42 km eastward at depth of 69 km on Nov. 29, 2013. The magnitude was 4.8. The spectrums of 5 seconds records for P-parts, S-parts and coda parts (after the times twice larger than S-time) are displayed in Figure 4.

There are several remarkable features in the waveforms on the filled slope. First, we observed amplifications on the filled slope in every component as well as in every type of seismic waves. Second, the amplification was so large in the updown component for S-waves that its amplitude almost equaled to those in horizontal ones. This is considered to be mainly due to the amplifications for 5-8 Hz and around 20 Hz from spectral analysis. Lastly, the level of the pore pressure increased by 0.02-0.03 kPa, when the large S-waves arrived.

4. Amplification of the updown component for S-waves

In Figure 5, we arranged the seismic waveforms and pore pressure records at Fusuma-cho Park for some of the events shown in Figure 2. At a glance, we found, for all the events, that the amplitudes in the updown component equaled to those in the horizontal, as was the case with the event on Nov. 29, 2013 (Section 3). In Figure 6, the spectral ratios of updown components for S-waves on the filled slope to those at the sediment ground were shown for all the events analyzed. All the spectral ratios have peaks remarkably at 5-8 Hz and slightly at around 20 Hz. This indicated that such amplification take place regardless of the back-azimuths or magnitudes of the events. Therefore, shallow portion of the filled slope can be related to such amplification.

The ground water level was estimated to be at depth of 2-3 m. Boring data show that alluvium has a

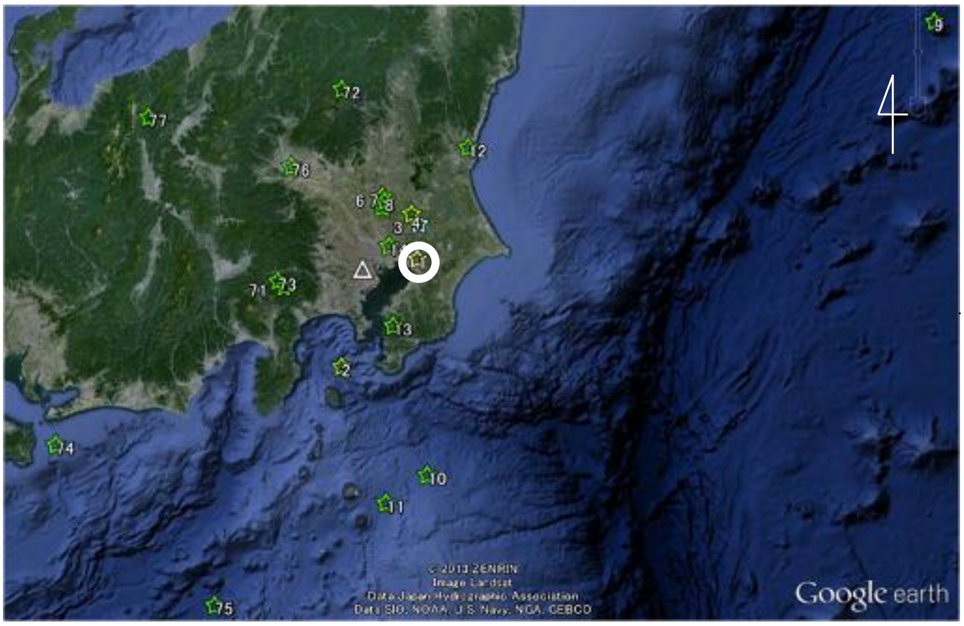

Figure 2: Map showing the observation sites (a triangle) and epicenters used in this analysis (stars). The seismic event on Nov. 29 is shown by a white circle.

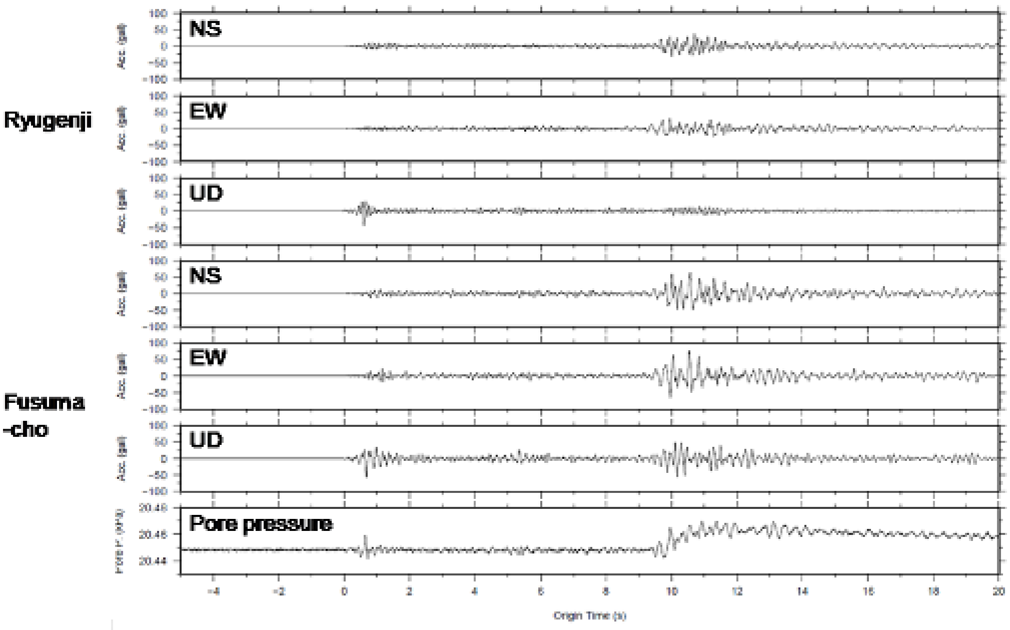

Figure 3: Seismic waveform and pore pressure records for the event on Nov. 29, 2013.

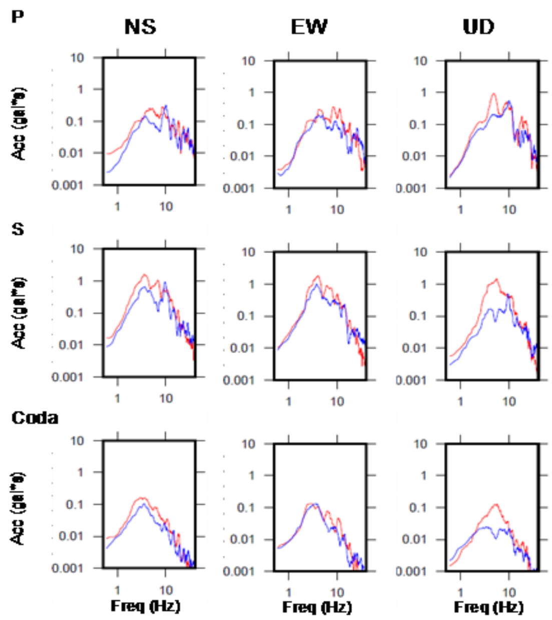

Figure 4: Spectrum of the seismic waveform records on the filled slope (red) and on the sediment ground (blue) for the event on Nov. 29, 2013.

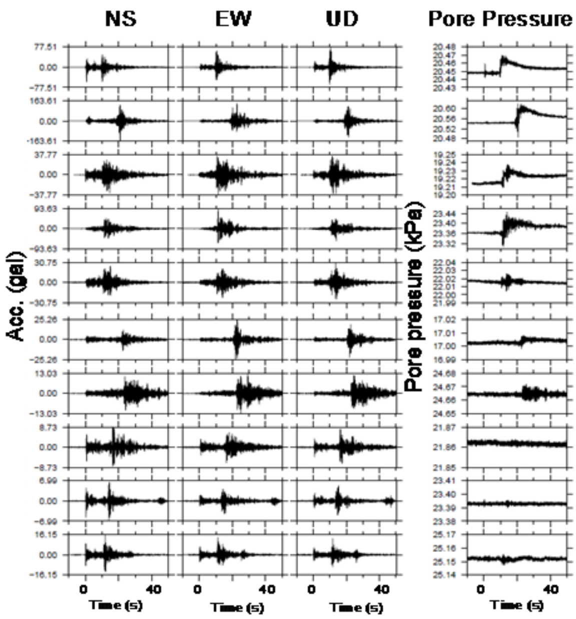

Figure 5: Seismic waveform and pore pressure records on the filled slope for several events whose epicenters are shown in Figure 2. The maximum acceleration was less than 10 gal in the second and third events from the bottom.

thickness of 4-5 m beneath the fills of 4-5 m thickness. Taking the 1/4 wavelength law into account, the two peaks in the spectrum may derive from the converted waves from S to P on the top of the ground water and at the bottom of alluvium.

5. Long-term pore pressure response to strong ground motions

According to Figure 5, the long-term increase in pore pressure accompanied with S-wave arrival was observed when the maximum acceleration was over ~10 gal. Kamai (2011b) already found this phenomenon and interpreted that the soil became plastic to be partly collapsed. We did not observe such a trend in pore pressure for P-wave arrival,

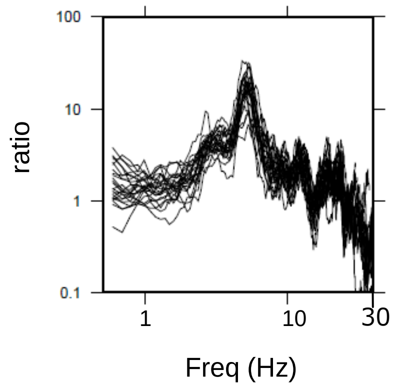

Figure 6: Spectral ratios of updown components for S-waves on the filled slope to those at the sediment ground were shown for all the events analyzed.

though the maximum acceleration for event 1 exceeds 40 gal. This can be interpreted that the partial collapse of soil took place in accompany with shear waves and not with compressional waves.

6. Relationship between pore pressure and air pressure

In general, air pressure increase lowers the ground water level, resulting in the decrease of values of pore pressure. In Figure 7, we show the relationship between air pressure and pore pressure during one hour in which the event on Nov. 29 was included.

We can see a linear trend of the relationship between air pressure and pore pressure, however the trend is different before (blue) and after (red) the mainshock shaking. This also implies that the soil partially collapsed to resultantly change the ratio with which the soil and the ground water support the sediments above.

7. Conclusions

Seismic waveforms and pore pressure records were examined to elucidate the characteristics of the shaking and the ground water response in the filled slope. The analysis revealed that updown component was dominant in the S-part, equivalent to the horizontal ones, probably due to the existence of alluvium and saturated layers in the filled slope. This is crucially important to estimate the slope stability during shaking, though only horizontal accelerations are considered in the stability analysis currently used. Moreover, it was found that shear waves with the acceleration larger than 10 gal made the soil plastic. In the next step, we should figure out that the alluvium and the ground water layers actually produce large amplification at 5-8 Hz and around 20 Hz through simulation.

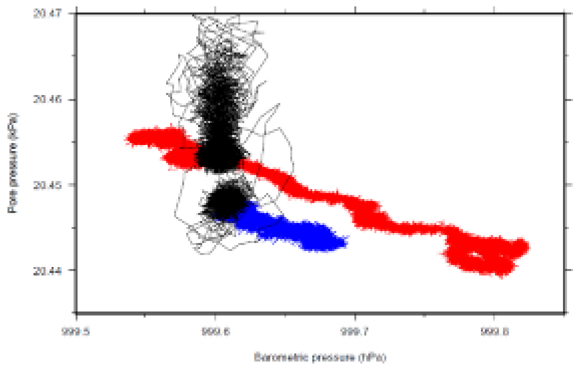

Figure 7: Relationship between barometric pressure and pore pressure during one hour in which the event on Nov. 29 was included. The color shows the time periods: before shaking (blue), during shaking (black), and after shaking (red).

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