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EFFECTS OF DYNAMIC PROPERTIES OF PEAT ON STRONG GROUND MOTIONS DURING 2004 MID NIIGATA PREFECTURE EARTHQUAKE

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ABSTRACT

Strong ground motions greater than or equal to 1 G were recorded at three stations in Ojiya city during the 2004 Mid Niigata Prefecture earthquake. Both the peak ground acceleration of 13.08 m/s^2 and the peak ground velocity of 1.29 m/s recorded at K-NET station on soft soil were 1.5 times greater than those at JMA station on soft soil as well as those at the other rock outcrop station (SSI) in the same city. Those at K-NET during earthquakes with less intensities, on the contrary, tended to be smaller that those at JMA. Field investigation including boring, PS logging and laboratory tests on undisturbed samples obtained from the sites reveals that the near-surface peat at K-NET has a very low shear wave velocity of 50 m/s^2 but shows the weakest nonlinearity among others. Nonlinear dynamic analysis is conducted using the detected soil profiles and properties with the recorded rock outcrop motions at SSI to simulate the ground motions at the two stations. It is shown that nonlinear dynamic properties of near-surface soil, in particular, the weakest nonlinearity of peat at K-NET, might have played an important role on the difference in ground motions between K-NET and JMA during different level of shaking.

Keywords: earthquake, dynamic properties, nonlinear, peat, surface soil

INTRODUCTION

The Mid Niigata Prefecture earthquake (M_W 6.6) that struck the central part of Niigata prefecture, Japan on October 23, 2004, caused many landslides and severe damage to many wooden frame houses and triggered many landslides, resulting in more than 50 fatalities and 4,800 wounded. At the same time this earthquake provided a large number of strong ground motion records. Particularly interesting is the difference in recorded strong motion between three stations in Ojiya city, located about 7 km west of the epicenter. These include K-NET (Kyoshin NET) and JMA (Japan Meteorological Agency) stations on soft soils, and SSI (Suisen House) on outcrop rock. Both the peak ground acceleration of 13.08 m/s^2 and the peak ground velocity of 1.29 m/s recorded at K-NET station were 1.5 times greater than not only those at the rock outcrop station (SSI) but also those at JMA on soft soil. The peak ground accelerations at K-NET during earthquakes with less intensity, in contrast, tend to be equal to or less than those at JMA station. Based on laboratory test on undisturbed sample obtained from the sites and back-calculation of strain-dependent properties of surface soils using the strong motion records observed at the three stations, Tokimatsu and Sekiguchi (2006) indicated that the dynamic properties of near-surface soil at K-NET and JMA were quite different with each other and this could cause the difference in observed ground motion between the two stations.

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The objective of this study is to further evaluate the effects of local site conditions on the ground motion characteristics during the Mid Niigata Prefecture earthquake, based on a nonlinear dynamic analysis using the soil profiles and properties determined in the previous studies for the two stations.

GEOLOGICAL AND GEOPHYSICAL CONDITIONS AT THREE STATIONS IN OJIYA

Figure 1 shows a geomorphological land classification map (Niigata Prefecture 1977) of the central part of Ojiya in which the three strong motion stations are located. The central part of Ojiya is situated on the left side of the Shinano River running north towards the Sea of Japan through the Niigata Plain. Gravel terraces dominate in the area, with several lower valley plains formed by the erosion and sedimentation of the tributaries of the Shinano River. On the gravel terraces, cohesive soil or sandy soil dominates from the ground surface to a depth of 2-5 m, which is in turn underlain by Holocene gravel and Pleistocene rock called Uonuma group. On the valley plains, in contrast, cohesive soil or sandy soil of a thickness of 2-5m dominates, which is directly underlain by the rock of Uonuma Group.

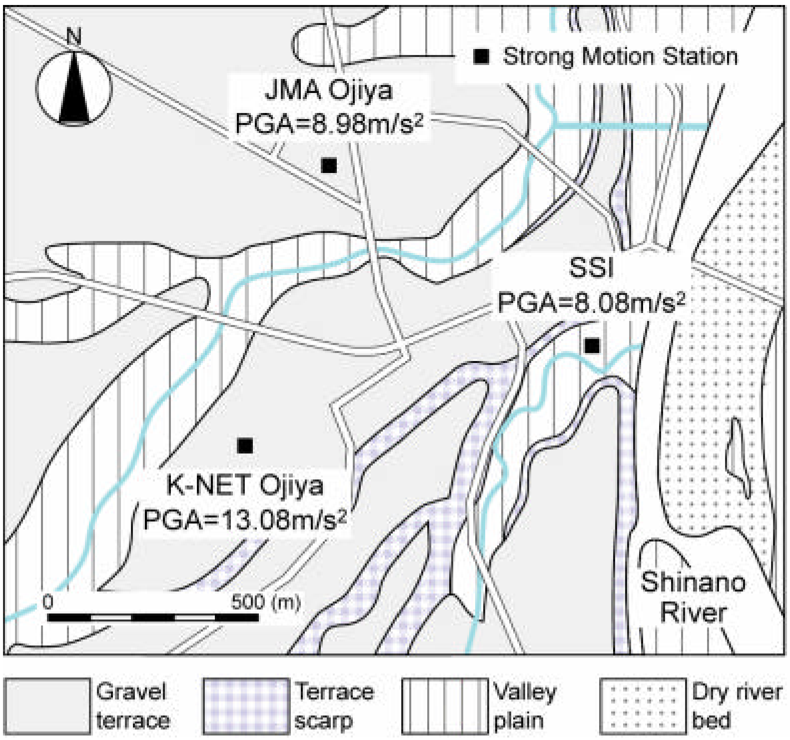

Figure 1. Geomorphological land classification map of the central part of Ojiya city.

Geological logs are available for the three stations, but PS logs are available only for K-NET and SSI stations. In addition, nonlinear soil properties of soft surface soils at K-NET and JMA, which might have had significant effects on the ground motions, were unknown. Field investigation including boring, sampling, and PS logging was, therefore, conducted to determine the characteristics of the soft soils and the Holocene gravel down to a depth of about 7 m at K-NET and JMA (Tokimatsu et al., 2006).

Figure 2 shows the geological logs and the shear wave velocity logs at the two stations together with those at SSI. The geological logs deeper than 7 m are based on previous investigation made by other institutions (K-NET and Ojiya Regional Fire Department). The surface soil to a depth of 3 m at K-

NET station is extremely soft, consisting of silty clay and peat with V_s as low as 50 m/s. The surface soil to a depth of 3 m at JMA station, in contrast, consists of silty clay and sandy silt with V_s of about 100 m/s. Underlying below the 3-m thick surface layer at each station is a gravel layer with V_s of about 400 m/s, which is underlain by Pleistocene rock (Uonuma Group) with V_s of about 400 m/s[2], which occurs at a depth of about 13 m. Thus, the impedance contrasts between the 3-m thick surface soil and the gravel layer at both stations are relatively high. The surface soil to a depth of 2 m at SSI site consists of sandy silt, which is underlain by Pleistocene rock with V_s of 430 m/s. The shear wave velocity of the Pleistocene rock at SSI is almost the same with those of the stiff gravel layer occurring at 3 m depth at K-NET and JMA.

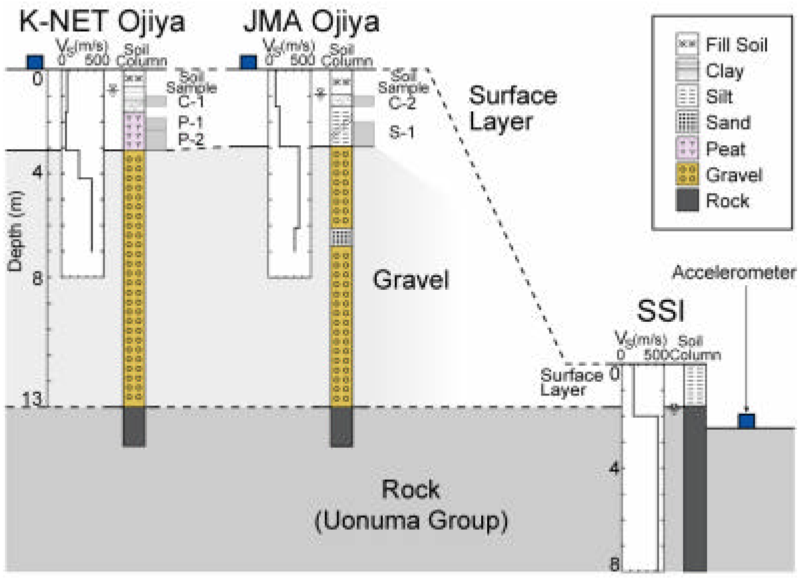

Figure 2. Geological and geophysical logs at three stations in Ojiya. (Tokimatsu and Sekiguchi, 2006)

The strong motion seismometers at K-NET and JMA have been installed on the ground surface, while that at SSI station near the base of an isolator of a building founded on the Pleistocene rock occurring at about 4 m depth below the ground surface. Thus the strong motions recorded at SSI are considered to be rock outcrop motions.

GROUND MOTION CHARACTERISTICS AT THREE STATIONS

Strong ground motions during the main shock and 17 aftershocks as well as one before the main shock were successfully recorded at more than two stations including SSI and are available for this study. Figure 3 (a)-(c) compare the velocity response spectra with a damping ratio of 5 % for the stronger EW components of the main shock and several aftershocks. The velocity response spectra at SSI in the periods less than 0.1 s are not shown because the accelerometers recorded at this station are insensitive in that period range. A prominent spectral peak appears in most velocity response spectra at K-NET and JMA, with its spectral peak period increasing with increasing intensity of ground shaking or spectral amplitude. Such trends, however, do not exist in most of the velocity response spectra at SSI. This suggests that the ground motions at K-NET and JMA could reflect nonlinear local site effects but those at SSI are associated with those observed at a rock outcrop site.

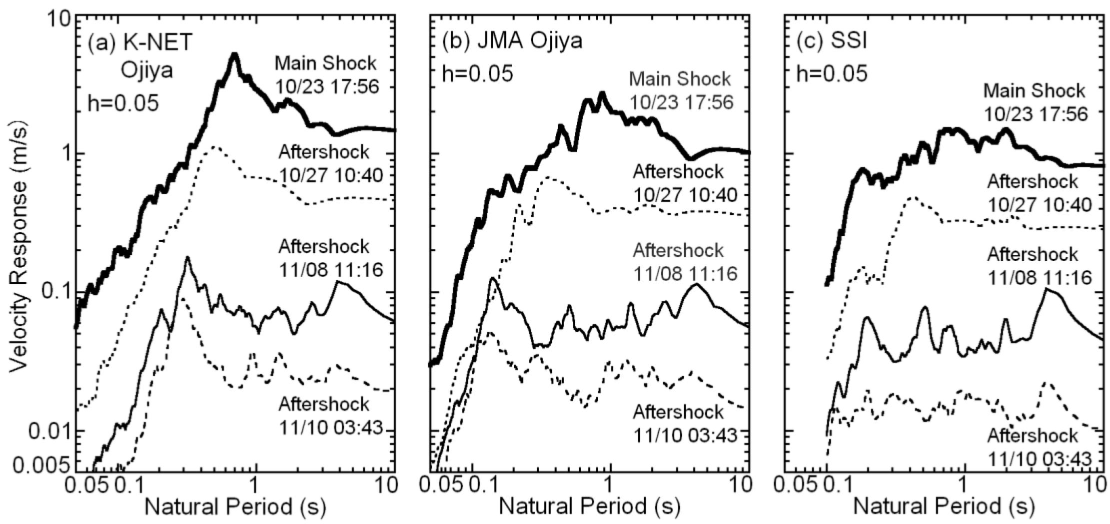

Figure 3. Velocity response spectra of EW components at three stations during several earthquakes.

Figure 4 (a)-(c) compare the peak ground accelerations (PGA) of the recorded strong motions between two of the three sites (Tokimatsu and Sekiguchi, 2006). Comparison of Figs. 5 (b) and 5 (c) indicates that the peak ground accelerations at the soft soil sites (K-NET and JMA) are, on the average, about 40 percentage points greater than that at the rock outcrop site (SSI), except for the main shock in which the PGA at JMA is almost equal to that at SSI. As a result, the PGA at K-NET tends to be smaller than that at JMA (Fig. 5(a)) during small intensity earthquakes but equal to or greater during the main shock. The change in relative magnitude of peak ground acceleration with shaking intensity abetween the two sites suggests that the strain-dependent nonlinear properties of surface soils are different between the sites.

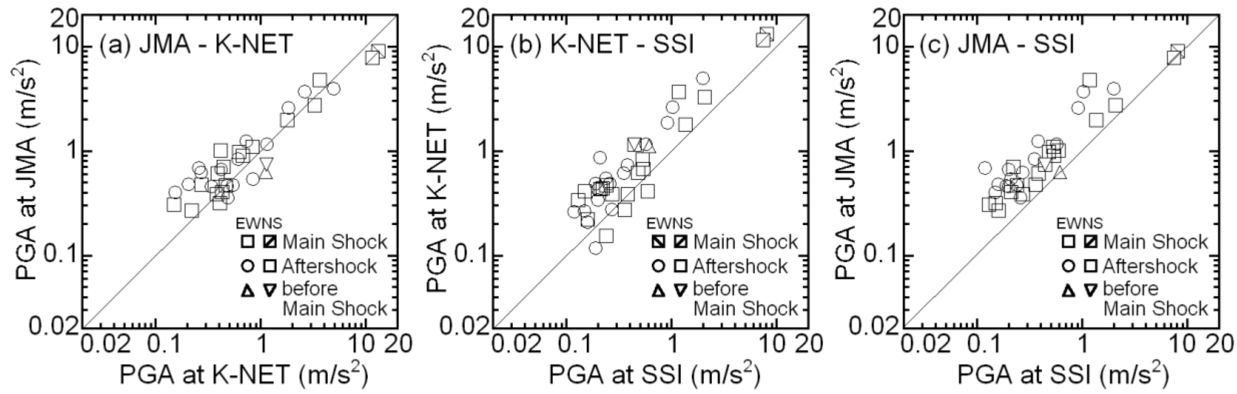

Figure 4. Comparison of observed peak ground accelerations between two of three stations. (Tokimatsu and Sekiguchi, 2006)

NONLINEAR DYNAMIC PROPERTIES OF SURFACE SOILS FROM LABORATORY TEST

To examine nonlinear dynamic soil properties of the surface soils at K-NET and JMA, cyclic torsion shear tests were conducted on hollow specimens, 100 mm high having 70 mm outer and 30 mm inner diameters, that were trimmed from the samples obtained at the sites. Each specimen was saturated and isotropically consolidated under confining pressure as close as possible to the in-situ effective stress (Tokimatsu and Sekiguchi, 2006). The samples tested include silty clay (C-1) and peat (P-1, P-2) at K-NET and silty clay (C-2) and sandy silt (S-1) at JMA, the depths of which are shown in Fig. 2.

Figure 5 shows the relations of shear modulus ratio and damping ratio with shear strain for the specimens tested. Despite its very low shear wave velocity of about 50 m/s, the peat at K-NET (P-1, P-2) shows weaker nonlinearity than any other soil. Namely, the shear modulus ratio and damping factor at a shear strain of 1 % are about 0.5 and 10% for the peat, the values of which are equivalent to those of the other soils at a shear strain of 0.1 %, which is about one order of magnitude smaller than 1 %. The shear modulus ratio and damping factor at a shear strain of 1 % of the soils except the peat are as low as 0.1 and as high as 15-20 %, showing stronger nonlinearity. Similar weak nonlinear dynamic characteristics of peat have been presented elsewhere (Boulanger et al. 1996, Wehling et al. 2003).

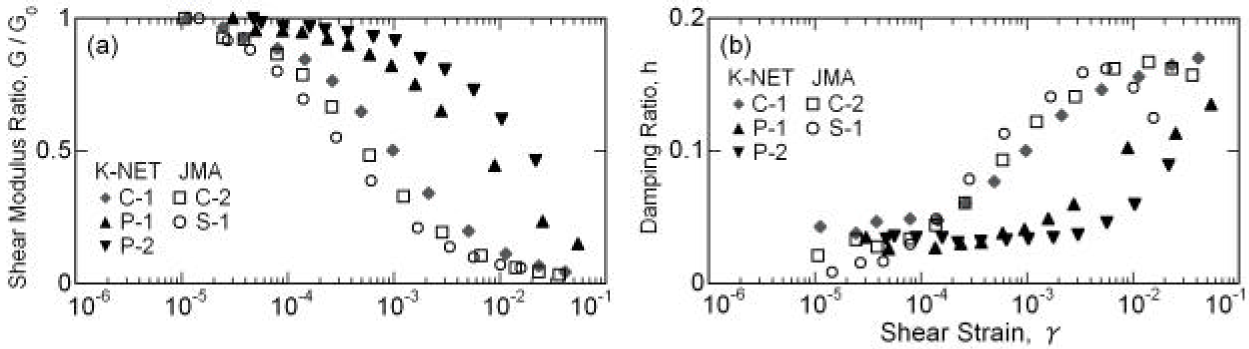

Figure 5. Relations of shear modulus ratio and damping ratio with shear strain for samples. (Tokimatsu and Sekiguchi, 2006)

MODELING OF SOIL PROPERTY FROM LABORATORY TEST

Figures 6 (a) and (b) shows the shear stress-strain relations and the effective stress paths of the peat (P-1) with shear strain of about 6 % from the laboratory test. Despite the large shear strain in excess of 5 %, the effective stress does not reach to zero and the stress strain curve shows cyclic mobility behavior, with relatively small hysteresis. This indicates that the peat shows peculiar dynamic soil properties that are quite different from those of any other soil. To simulate the results of the laboratory test of the samples at K-NET and JMA, Modified Ramberg-Osgood model was used to represent the stress strain curve and the bowl model presented by Otsuki et al. (1994) was used to take into account the effects of change in pore water pressure. The parameters of the models were optimized to fit the results of the laboratory tests. The computed shear stress-strain relations and effective stress paths of the peat (P-1) are shown in Figures 6 (c) and (d).

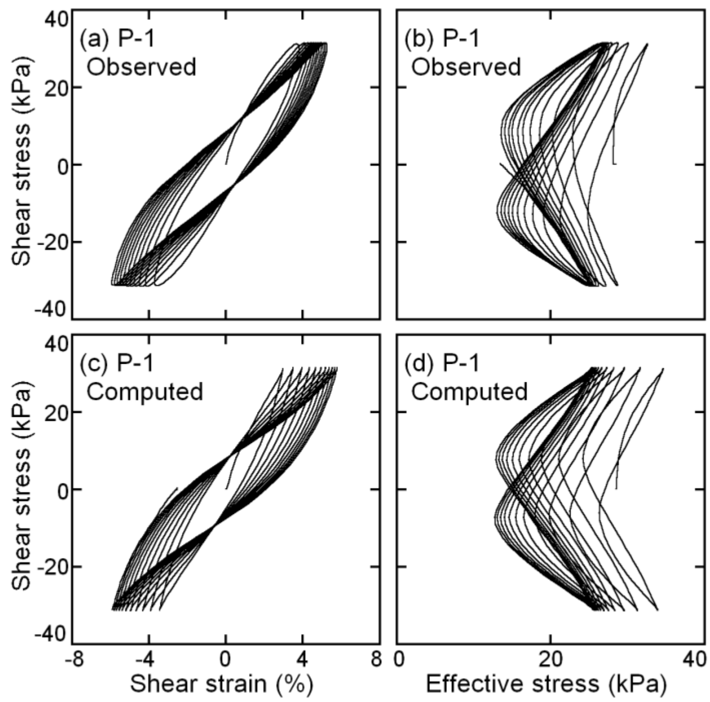

Figure 6. Observed and computed shear stress-strain relations and effective stress paths of the peat (P-1)

NONLINEAR EFFECTIVE STRESS ANALYSIS

To simulate the observed strong motions at K-NET and JMA during the Mid Niigata Prefecture earthquakes, one-dimensional nonlinear effective stress dynamic response analysis was conducted, with the nonlinear dynamic soil properties shown in Fig. 5, modeled according the procedure outlined in the previous section. The dynamic properties for the gravel below a depth of 3 m, which was not tested, were assumed to be those presented by Imazu and Fukutake (1986). The effects of pore pressure buildup on stress strain behavior were taken into account only for the near-surface layers between the ground water table and a depth of 3 m. The ground motions recorded at SSI were used as input motions to the base rock layer at a depth of 13 m (the top of the rock) or 3m (the top of the stiff gravel layer), shear wave velocities of which are almost the same with that of the outcrop rock at SSI.

Figure 7 compares the computed and observed ground surface acceleration time histories for the input base motion at a depth of 13m at K-NET and JMA for the main shock, together with that recorded at SSI. The computed time histories for both stations agree reasonably well with the observed ones.

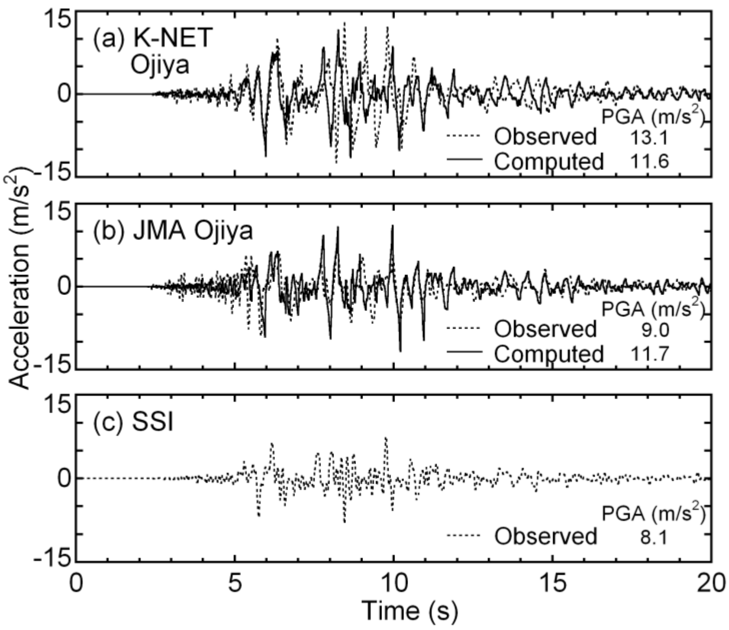

Figure 7. Comparison of computed and observed acceleration time histories for the main shock.

Figure 8 compares the velocity response spectra with a damping ratio of 5% of the observed and computed motions at the two stations for the main shock as well as the aftershock on 11/10/2004 03:43 for the input base motion at a depth of 13m and 3m. The velocity response spectra of the computed motions at both stations agree reasonably well with those of the observed motions. There exists insignificant difference between the two velocity response spectra for the input base motion at a depth of 13m and 3m, suggesting that the ground motions at K-NET and JMA were not affected by the dynamic properties of gravelly soils but by those of the near-surface soils, even though the gravelly soils exhibited nonlinear behavior.

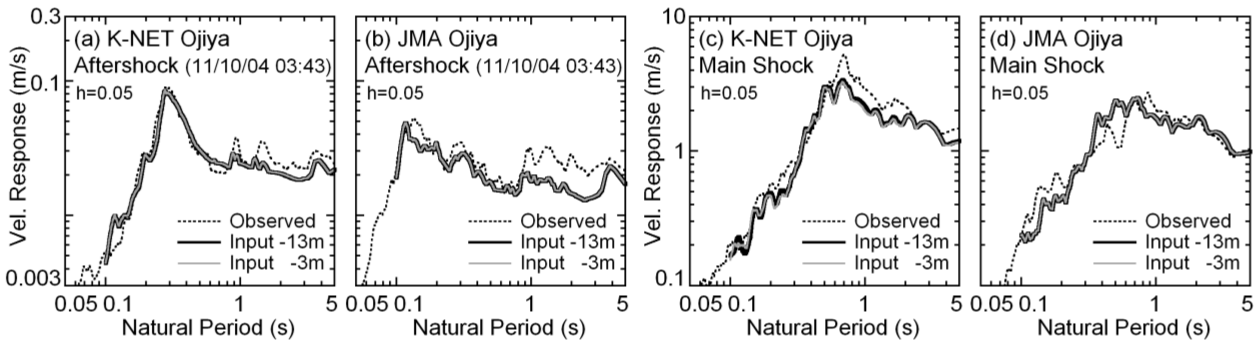

Figure 8. Comparison of computed and observed acceleration time histories for the main shock.

Figure 9 compares computed PGA between K-NET and JMA. The computed PGA at K-NET in a small intensity earthquake tends to be generally smaller than but that during the main shock is almost equal to or greater than that at JMA, the trend of which is consistent with that observed in Fig. 4(a).

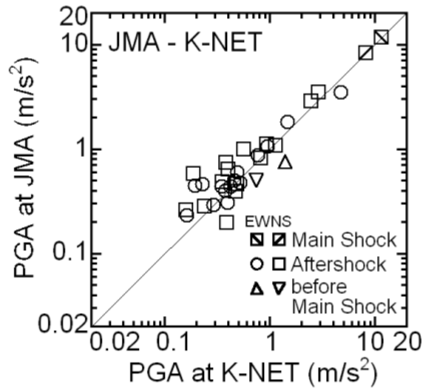

Figure 9. Comparison of computed peak ground accelerations between K-NET and JMA.

The above finding and discussions indicate that the near-surface soils to a depth of 3 m including their nonlinear soil properties, particularly the weak nonlinear properties of peat, significantly affected the difference in strong ground motion between K-NET and JMA during earthquakes with different intensities including the 2004 Mid Niigata Prefecture earthquake.

6. CONCLUSIONS

The effects of local site conditions on the strong ground motions during the 2004 Mid Niigata Prefecture earthquake were examined based on the nonlinear site response analysis with the dynamic properties modeled from the laboratory tests on samples obtained from the sites. Based on the results and discussions, the following conclusions may be made:

1. The strong ground motions at K-NET during the main shock were 1.5 times greater than those at JMA station on soft soil as well as those at the other rock outcrop station (SSI) in the same city. Those at K-NET during earthquakes with less intensities, on the contrary, tended to be smaller that those at JMA.

2. Field investigation including boring, PS logging and laboratory tests on undisturbed samples obtained from the sites reveals that the near-surface peat at K-NET has a very low shear wave velocity of 50 m/s^2 but shows the weakest nonlinearity among others.

3. The nonlinear dynamic analysis using the detected soil profiles and properties has simulated well the difference in strong motion between K-NET and JMA during different level of shaking and suggests that the difference in nonlinear properties of surface soils between the two sites and, in particular, the weak nonlinearity of peat at K-NET, might have had strong effects on the difference in strong motion between the two sites.

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The strong motion records as well as the geological and PS logs at SSI were provided by Ojiya Polyclinic, Mitsubishi Jisho Sekkei and Taisei Corporation.

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