RE-EVALUATION OF NONLINEAR SITE RESPONSE DURING THE 1964 NIIGATA EARTHQUAKE USING THE STRONG MOTION RECORDS AT KAWAGISHI-CHO, NIIGATA CITY

Kazuyoshi KUDO[1], Tomiichi UETAKE[2] And Tatsuo KANNO[3]

SUMMARY

We re-analyzed the strong motion records obtained at Kawagishi-cho apartment building aiming to understand the long period motion and nonlinear behavior of soils during the earthquake. It was a first experience that the strong motion records were acquired at the site where severely damaged due to liquefaction. It has been presumed that the long period motion appeared just after the short period motion was caused by liquefaction. We confirmed that the long period motion was S-wave arrival, therefore, the essential nature of the long period motion is attributed to the earthquake source. A rough estimation on non-linearity of ground during the Niigata earthquake is presented by considering a rocking motion as a soil-structure interaction. The rocking motion was only found in the short span direction and no significant difference between basement and roof in the long span direction. The transfer function for rocking motion can be given by a spectral ratio of roof motions to those of basement and it was computed at different time sections. A clear decrease of elastic modulus, as revealed by rocking motion of a building, was identified during the major shaking. However, a drastic change happened at a few seconds after the appearance of peak acceleration. This evidence is quite similar to the experience at Port Islands during Hyogo-ken Nanbu, Kobe earthquake. The long period motion of late (60-70seconds) arrivals was presumably surface waves. Both long-period motions of early (7 seconds) and late (60-70 seconds) arrivals are originated by earthquake source and propagation path. The effects of non-linearity of soil to long period motion were not essential.

INTRODUCTION

The strong ground motion records were recovered at Kawagishi-cho in Niigata city, Japan, during the Niigata earthquake (MJ=7.5) of June 16, 1964. They are well known as the first records of near-field motion from large earthquake in Japan and liquefaction of large scale was observed near the site. Many efforts have been made for interpreting the cause of liquefaction based mostly on viewpoints of geotechnical and/or soil dynamics by using the strong motion records at Kawagishi-cho (e.g., Seed and Idriss, 1967; Ishihara and Koga, 1981; Yoshimi et al., 1984, Tokimatsu, 1989). However, no interpretation has been made on wave types appeared in the strong motion records. In addition, the analyses of the records were limited within 50 seconds duration in the records, therefore, it is difficult to discern the later arrivals of waves. The record at the roof of building has rarely used, therefore, simultaneous use both records is also our concerns. We digitized again during about 120 seconds for the record at the basement and about 90 seconds for the one at the roof of a four stories RC apartment building. Our major object is to describe wave types appeared in the records and to understand the nonlinear behavior of ground during the earthquake.

As it has been indicated in the previous studies, the most distinguishing feature of the strong motion records is that the long period motion, say 5 to 6 seconds, is predominated. If the long period motions were caused due to decreasing of elastic constants of soil and/or liquefaction as suggested by Seed and Idriss (1967) and Tokimatsu

[1] *Earthquake Research Institute, The University of Tokyo, Tokyo, Japan E-mail: kudo@eri.u-tokyo.ac.jp*
[2] *Power Engineering R&D Center, Tokyo Electric Power Company, Yokohama, Japan Email: t0666057@pmail.tepco.co.jp*
[3] *Graduate School of Engineering, The University of Tokyo, Tokyo, Japan, E-mail: kanno@eri.u-tokyo.ac.jp*

(1989), the long period motion as an issue in earthquake engineering will be put forth to a very local site effect. On the contrary, if it was due to the earthquake source and/or the basin effects with deep sediments, the problems will be regional scale or essentials of earthquake engineering and strong motion seismology

EARTHQUAKE AND STRONG MOTION DATA

Niigata earthquake of June 16, 1964

The magnitude 7.5 earthquake occurred at 38.35°N, 139.18°E, sea-off 40km north of Niigata City, at depth of 40 km, on June 16, 1964 (Japan Meteorological Agency). It brought severe damage of buildings due to liquefaction in a wide area in Niigata City and the vicinity, fire in large storage oil tanks, collapse of bridge and others. The source model of this earthquake is now controversial on the fault plane. Hirasawa(1965), Aki(1966), Abe(1975), Ruff and Kanamori (1983), Kusano and Hamada (1991) and Matsuhashi et al. (1987) support the high angle thrust fault of west hanging wall, while Stake and Abe (1983), Mori and Boyd (1985) and Fujiwara and Seno (1985) suggest the low angle thrust fault of east hanging wall. The epicenters of main- and after-shocks and the location of the observation site are shown in Figure 1.

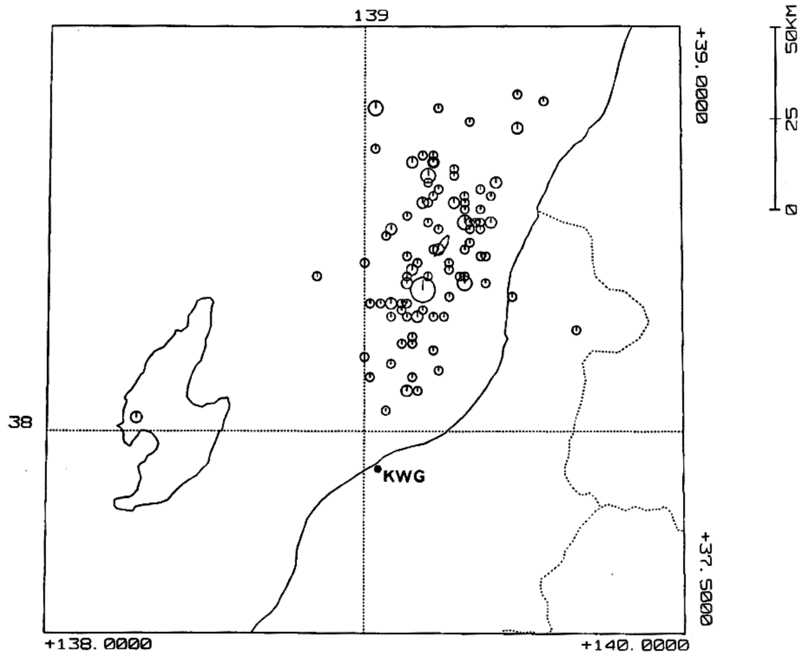

Figure 1: Location map of main and aftershocks of the 1964 Niigata earthquake and the strong motion observation site, Kawagishi-cho (KWG) in Niigata City.

Strong motion records observed at Kawagishi-cho, Niigata

Strong motion records were obtained at the basement and roof in a four stories RC apartment building (long span=37.3m, short span=7.2m, hight=13.3m) at Kawagishi-cho, Niigata City during the 1964 Niigata earthquake. The instruments were a SMAC-A type accelerograph at the basement (B1F) that were situated –2 m from the ground level and DC-type accelerograph at the roof (RF). The digitized data have already been used in earthquake engineering society (e.g. Tokimatsu, 1989). We digitized again them about 120 and 90 seconds for the basement and roof records, respectively, for aiming to discuss wave types found in the records and nonlinear effects during the shaking. Taking into account the digitizing error, we used band-pass (0.1–10 Hz) filter through the analyses including in the correction processes for instrumental responses. Thus obtained acceleration, velocity and displacement time histories at the basement and the roof are shown in Figures 2 and 3, respectively. The first 4.3 seconds of a vertical component was not recorded. The RF accelerograph has no vertical component. There was no absolute time signal in both recordings, therefore, we are obliged to assume each triggering time by comparing the shapes of both recordings.

Figure 4 shows the acceleration time histories of the first 13.5 seconds by comparing with both horizontal components at B1F (solid line) and RF (dotted line). The triggering time at RF was presumably assigned to be

3.54 seconds for both horizontal components after that of B1F. It is interesting that both EW components have surprisingly less difference compared with NS ones.

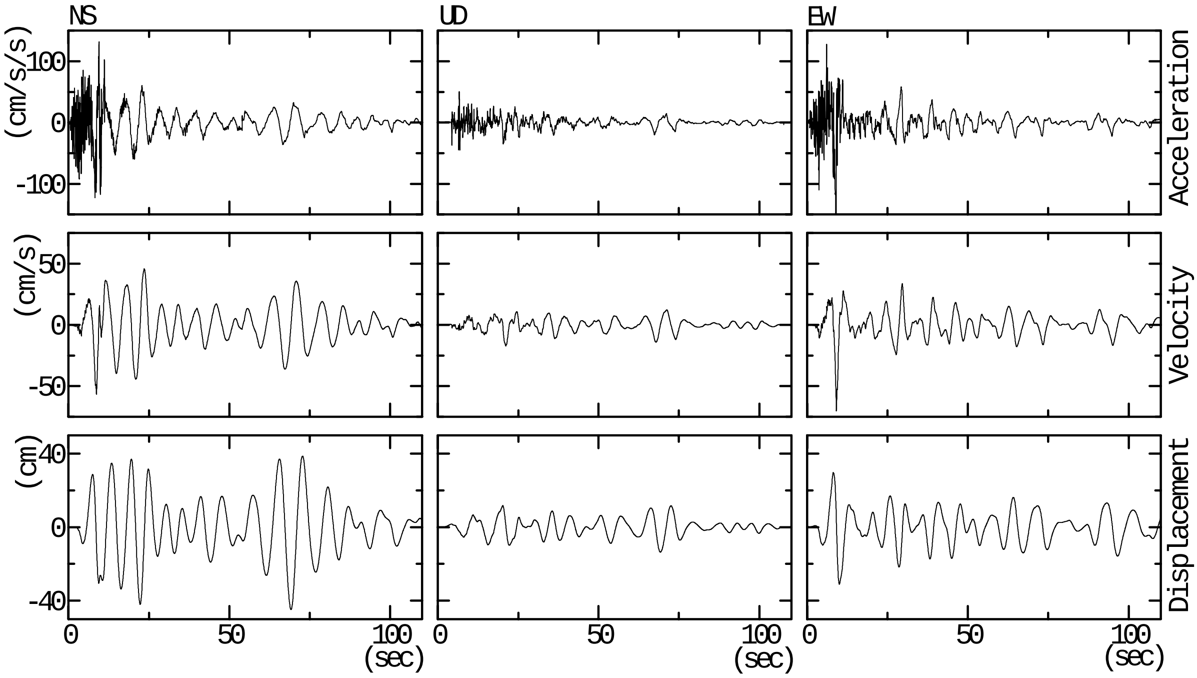

Figure 2: Processed acceleration, velocity and displacement observed at B1F in Kawagishi-cho apartment building from the 1964 Niigata earthquake.

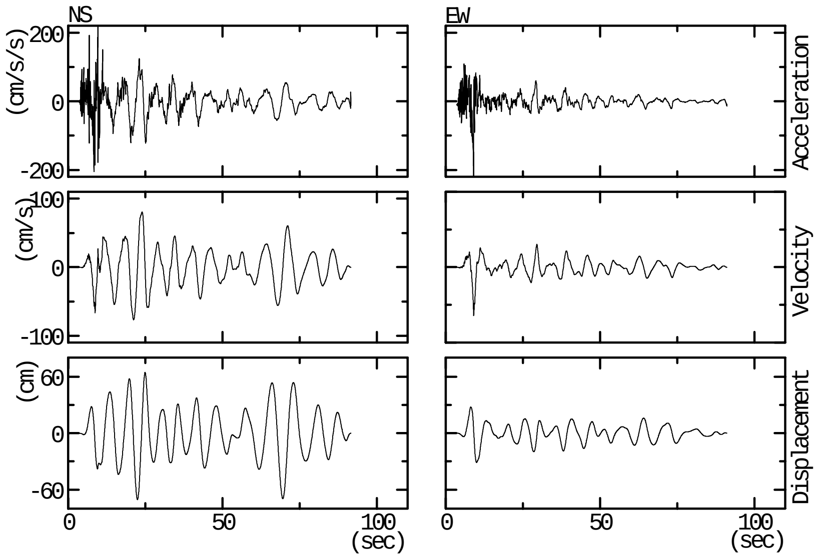

Figure 3: Processed acceleration, velocity and displacement observed at RF in Kawagishi-cho apartment building from the 1964 Niigata earthquake.

Arrivals of long period motion

The long period motion appeared at around 7 seconds after the triggering. The Niigata observation station of Japan Meteorological Agency (JMA) was located at 1.5 km east from the strong motion observation site. The S-P time at the JMA station was 7.1 seconds, therefore, it is very consistent that the long period motion at around 7 seconds found in the acceleogram is the S-wave arrival and the accelerograph at B1F started recording due to the onset of P-wave arrival.

Figure 5 shows the horizontal particle velocities dividing the time sections into two parts during 12 seconds. The particle motion of early 6 seconds shows a linear oscillation roughly directed to the source. The later particle velocity shows as if it is rotating. Simultaneous arrivals of SH- and SV- wave are consistent with the observation. The particle motions confirm that the first part is P-wave arrivals and the second one is S-waves. The predominated period of 5-6 seconds of S-wave is quite familiar from a large earthquake of magnitude 7.5.

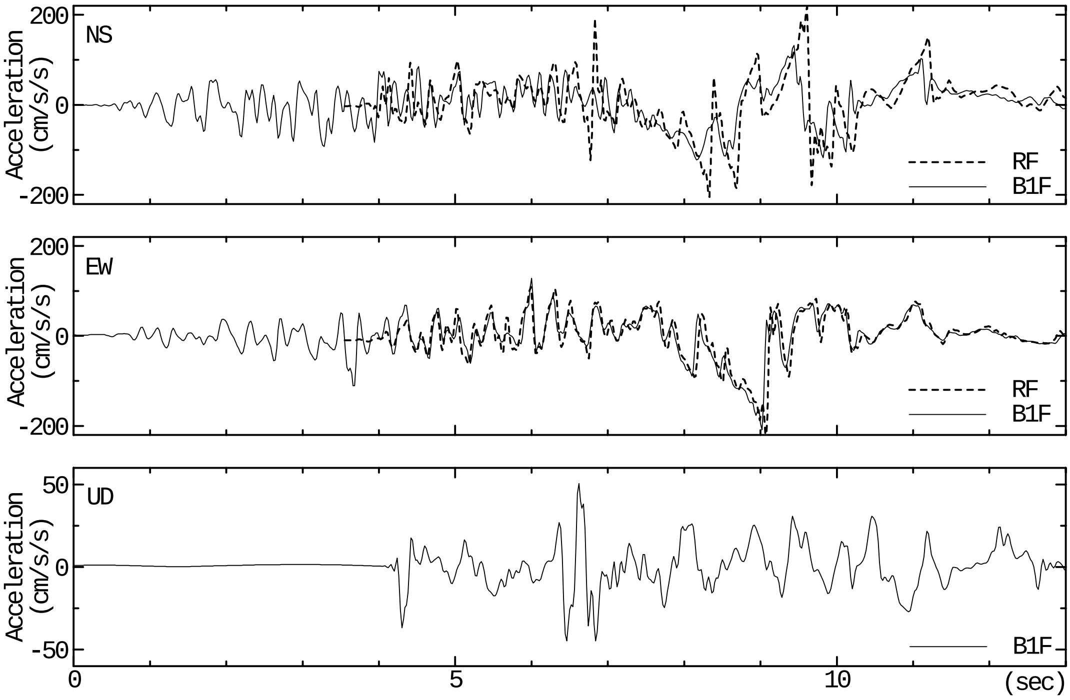

Figure 4: Simultaneous plots of early 13 seconds acceleration at B1F (solid line) and at RF (dotted line).

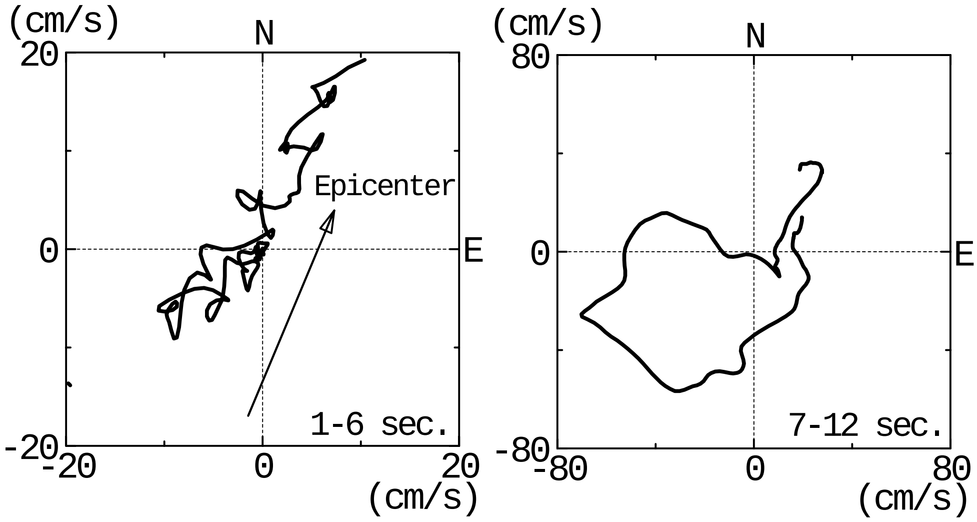

Figure 5: Horizontal particle velocities dividing the time sections into two parts during 12 seconds.

DECREASE OF THE GROUND ELASTICITY

It is very clear evidence that no significant difference was observed between B1F and RF motions of long span direction (EW component), therefore, the behavior of the building can be interpreted as only a translation movement. On the contrary, the rocking motion of the building was predominated as indicated by the records of short span direction (NS component). Figure 6 shows the simultaneous plots (3.5 seconds after the onset at B1F) of the acceleration time histories of NS and EW at B1F (solid lines) and those at RF (dotted lines) and spectral ratios of RF to B1F at different time sections. The spectral ratios for short span (NS) motions at different time windows varies significantly in both magnitude and predominant period, while those of long span (EW) motions keep almost identical for all time windows except for very high frequencies.

If we assume a simple sway-rocking model as a soil-structure interaction, the spectral ratio of RF motion to B1F motion gives the transfer function of rocking motion. Spectral ratios, as shown in Figure. 6, the predominant period of short span tends to long period associated with the lapse of time. The first section, 3.5-7 seconds, which corresponds to P-wave arrivals has a sharp peak at 3 Hz. Tajimi (1968) interpreted as that this peak was due to rocking motion, because no significant motion at around 3 Hz was found in B1F records. The second section, 7-12 seconds, which corresponds to S-wave arrivals and produced peak acceleration of 200 cm/s/s at B1F has two or three peaks. The reason why three peaks appeared is uncertain, but at least two peaks (2.4 and 1.4 Hz) at lower frequency than the one of the first section is an indication of decreasing of elastic modulus of ground related to rocking motion. The third sections, 12-32 seconds, shows drastic change of peak frequencies (1.4 and 0.7 Hz) and spectral amplitude ratio. The fourth section, 32-52 seconds, has a single peak at 0.8 Hz, however, later sections do not represent any significant peaks and spectral amplitude ratios are relatively small.

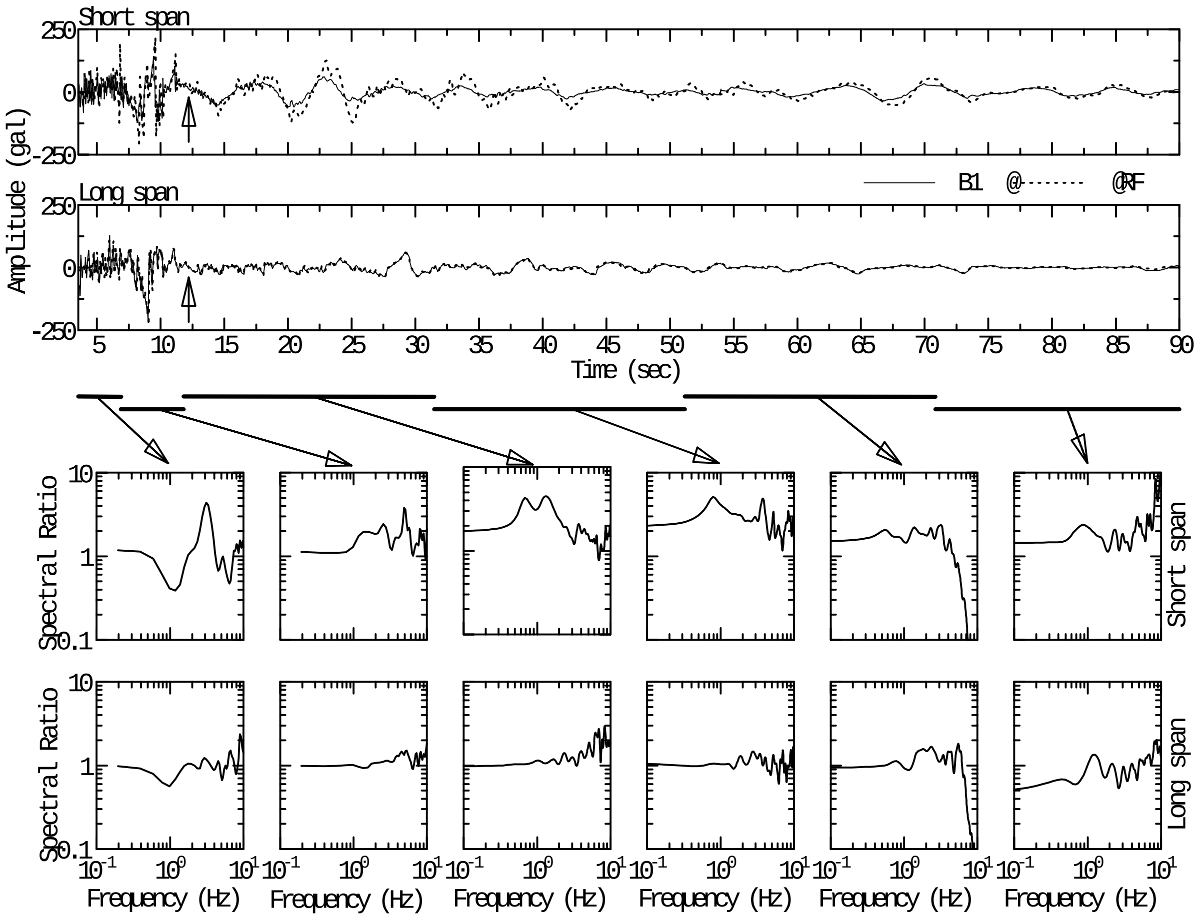

Figure 6: Simultaneous plots of B1F and RF acceleration time histories and spectral ratios of RF to B1F that give transfer function of rocking motion due to soil-structure interaction were computed for different time windows.

It will be valid to simply estimate that the first section represents no effects of non-linearity of ground and the elastic modulus decreased to 64 % (2.4 Hz) – 22% (1.4 Hz) during the second section. The drastic change happened at the third section when the elastic modulus decreased to 22-5% (0.7 Hz). This stage may plausibly correspond to the onset time of liquefaction at the site. The time will be 3-4 second later after the peak acceleration was observed.

Aguirre and Irikura (1997) reported the relation between the strong motion records and liquefaction observed during the 1995 Hyogo-ken Nanbu earthquake, Kobe. The onset of liquefaction was 3-4 seconds later after the S-wave arrival. We may conclude that liquefaction happened similarly at both sites with a few seconds after the S-wave arrival of large amplitudes.

LONG PERIOD MOTION OF LATER ARRIVALS

Figure 7a and 7b show results of multiple-filter moving-window analysis applied to the ground velocities of radial and vertical components, respectively. Absolute amplitudes of vertical motion are relatively small compared with the radial motion, however, patterns of running spectra are quite similar each other. The large amplitudes of later arrivals have predominant period around 7-8 seconds and significantly different from the one of S-waves (5-6 seconds). Taking into account the source process time of the Niigata earthquake, large amplitudes of velocity and displacement found in radial component earlier than 40 seconds are presumably S-waves. Low magnification displacement records recovered at JMA stations at regional distances (e.g. Tokyo, Mito, Gifu) represent also S-waves having predominant period of 5-6 seconds. The low magnification displacement-meter have a natural period of 5-6 seconds, therefore, we have to care the real ground motion. However, the record at Tokyo that was carefully analyzed represented the dominated motion around 6 seconds (Sato *et al.*, 1971).

Niigata City is located in a large basin consists of thick quaternary and tertiary sediments. The ground motions at Niigata City have been sometimes predominated by long period (5-15 seconds) surface waves. During the 1983 Nihonkai-chubu, oil sloshed from the huge oil tanks at Niigata district, even the distance from the source was about 300 km. Kudo and Sakaue (1984) reported the damage of oil tanks and the reason why long period motion was predominated in and around Niigata City. Analyzing the strong motion records, they interpreted the long period motion predominated by the surface waves due to thick (3-4 km) sedimentary layers of low S-wave velocity.

Available strong motion records recovered near Niigata City are only at Kawagishi-cho, therefore, we cannot go into detail with sufficient evidence. However, running spectra show a plausible dispersion of group velocity of about 0.7-0.6 km/sec at around 7-8 seconds, assuming the same source of body waves. This is not necessarily consistent with the group velocity of Rayleigh waves in Niigata basin estimated by Kudo and Sakaue (1984), however, the group velocity minimum of 0.5 km/s at a period 6 seconds is suggested. Mori and Boyed (1985) indicated the second event 10 seconds after the first events. The discussing phases are 40-50 seconds later than the initial S-wave arrival, so that the possibility of later arrivals due to the second event is very small. Figure 7 shows a running spectrum of a transverse motion. No clear evidence was found in later arrivals as the cases of vertical and radial components.

DISCUSSION

The strong motion records at Kawagishi-cho from the Niigata earthquake was obtained more than thirty years ago. The quality of digital data is not necessarily good compared with the recent digital recordings. However, it is very rare case that the records were obtained at the site where liquefaction occurred. Therefore, an additional study using the records is still useful by a help of recent investigations.

As inferred from a excellent data set at Port Island during the Hyogo-ken Nanbu earthquake (Aguirre and Irikura, 1997), decrease of high frequency motion near the surface due to nonlinear behavior of soils and/or liquefaction was very significant. We have no tool to directly confirm the evidence in case of Niigata, however, it is plausible, with a help of experiences in Kobe, that high frequency motion has to be decreased near the surface during the 1964 Niigata earthquake. We only would like to address that the long period motion was not produced by liquefaction but it was originally radiated from the source with some amplification by deep sedimentary layers. Therefore, the issues of long period motions cannot be solved by only surface soil nature but they are essentially concerns of earthquake source, propagation path and deep sediments of regional scale.

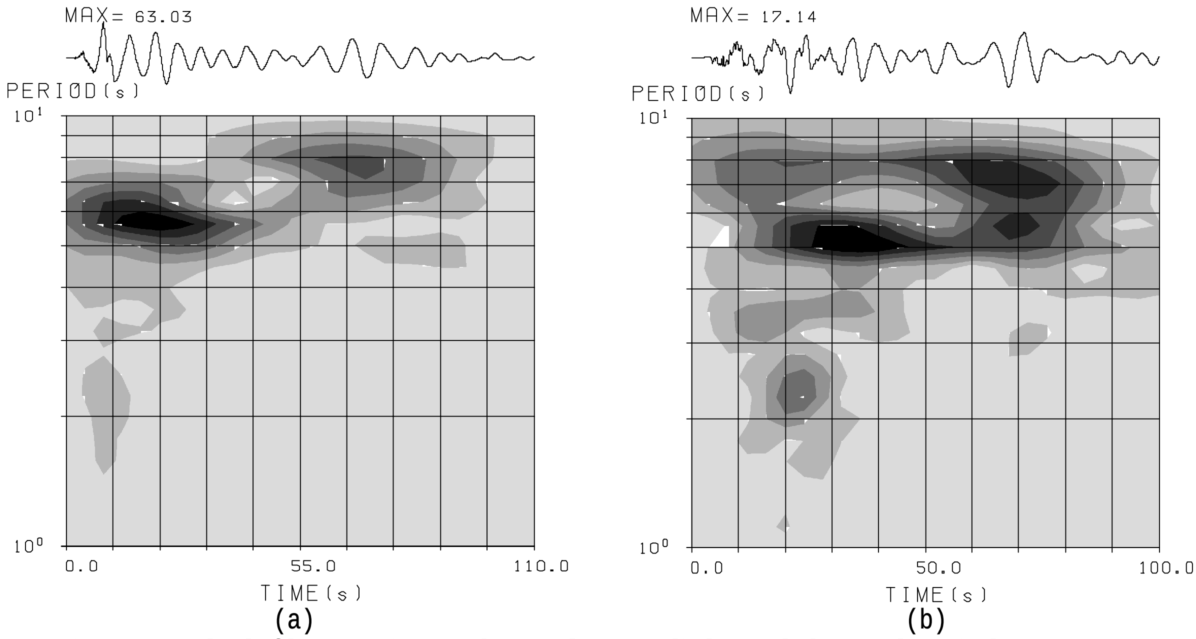

Figure 7: Multiple filter, moving window analyses applied to radial (a) and vertical components.

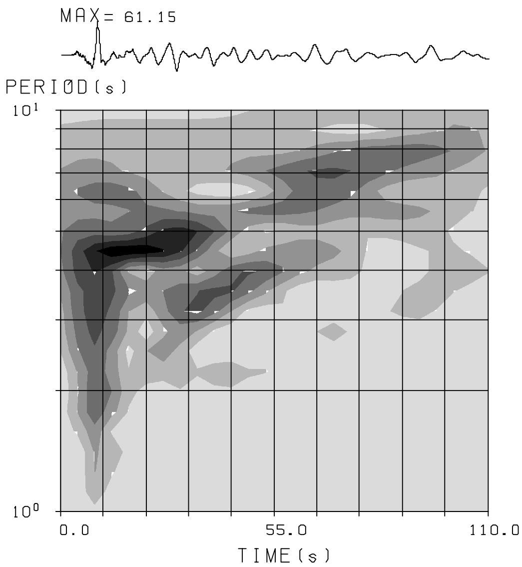

Figure 8: Multiple filter, moving window analyses applied to transverse components.

CONCLUSION

We analyzed the strong motion records obtained at Kawagishi-cho apartment building aiming to understand the long period motion and nonlinear behavior of soils during the earthquake. It was a first experience that the strong motion records were acquired at the site where severely damaged due to liquefaction. It has been presumed that the long period motion appeared just after the short period motion was caused by liquefaction. We confirmed that the long period motion was due to S-wave arrival, therefore, the essential nature of the long period motion is attributed to the earthquake source.

The significant differences between B1F and RF are found in only the short span direction (NS-component). Therefore, we recognized that the rocking motion was only predominated. A rough estimation on non-linearity of ground during the Niigata earthquake is presented by considering a rocking motion as a soil-structure interaction. The transfer function for rocking motion can be given by a spectral ratio of roof motions to those of basement and it was computed at different time sections. A clear decrease of elastic modulus of supporting ground related to rocking motion of a building was identified during the major shaking. However, a more drastic change happened at a few seconds after the appearance of peak acceleration. This evidence is quite similar to the experience at Port Islands during Hyogo-ken Nanbu, Kobe earthquake.

The long period motion of late (60-70seconds) arrivals was presumably surface waves. Both long-period motions of early (7 seconds) and late (60-70 seconds) arrivals are originated by earthquake source and propagation path. The effects of non-linearity of soil to long period motion were not essential. The issues of long period motions cannot be solved by only surface soil nature but they are essentially concerns of earthquake source, propagation path and deep sediments of regional scale.

Re-digitized strong motion data will be available to download: ***http//:kyoshin.eri.u-tokyo.ac.jp/SMAD/***

REFERENCES

Abe, K. (1975), " Re-examinatio of the fault model for the Niigata earthquake of 1964", *J. Phys. Earth*, 23, pp349-366.

Aguirre, J. and Irikura, K., (1997), " Nonlinerity, liquefaction, and velocity variation of soil layers in Port Island, Kobe, during the Hyogo-ken Nanbu earthquakes", *Bull. Seism. Soc. Am.*, 87,5,991244-1258.

Aki, K. (1966), " Generation and propagation of G-waves from the Niigata earthquake of June 16,1964. Part2. Estuimation of earthquake moment, release energy, and stress-strain drop from the G-wave spectrum", *Bull. Earthq. Res. Inst.*, 44, pp73-88.

Fujiwara, K. and Seno, T. (1985), "Redetermination of the aftershock distribution of the 1964 Niigata earthquake", *Zisin 2*, 38, pp259-261. In Japanese

Hirasawa, T. (1965), " Source mechanism of the Niigata earthquake of June 16, 1964, as derived from body waves", *J. Phys. Erath*, 13, pp35-66.

Ishihara, K. and Koga, Y. (1981), "Case studies of liquefaction in the 1964 Niigata earthquake", *Soil and Foundations*, 21,3,pp33-52.

Kudo, K. and Sakaue, M. (1984), "Oil-sloshing in the huge tanks at Niigata due to the Nihonkai-Chubu earthquake of 1983", *Bull. Earthq. Res Inst.*, 59, pp361-382. In Japanese with Enlish abstract

Kusano, F. and Hamada, N. (1991), " Re-investigation of hypocentral distribution of the 1964 Niigata earthquake and its aftershocks", *Zisin 2*, 44, pp305-313.

Matsuhashi, Y., Aburakawa, T., and Sato, H. (1987), "Horizontal displacements accompanied with the Niigata earthquake of 1964 and its fault model", *Zisin 2*, 40, pp619-622.

Ruff, L. and Kanamori, H. (1983), " The rupture process and asperity distribution of three great earthquakes from long period diffracted P-waves, *Phys. Earth Planet. Interior*, 31, pp202-230.

Mori, J. and Boyd, T. (1985), " Seismological evidence indicating rupture along an eastward dipping fault plane for the Niigata, Japan earthquake", *J. Phys. Earth*, 33, pp227-240.

Satake, K. and Abe, K. (1983), " A fault model for the Niigata, Japn earthquake oj June 16, 1964", *J. Phys. Earth.*, 31, pp217-223.

Sato, Y., Kotake, Y., and Shima, E. (1971), "Analysis of strong motion seismograms and the response of structures", *Zisin 2*, 24, pp248-265.

Seed, B. H. and Idriss, M. I. (1967), " Analysis of soil liquefaction: Niigata earthquake", *J. Soil Mech. And Foundation Div., Proc. ASCE*, SM3, pp83-108.

Tajimi, H. (1968), "Soil-structure interaction" in *Earthquake Enineering*, (ed. Kanai, Tajimi, Osawa, Kobayashi), Shokokusha, Japan, pp55-65. in Japanese

Tokimatsu, K.. (1989), "Damage of apartment building at Kawagishi-cho and the strong motion records due to the 1964 Niigata earthquake", *Proc. 1989 Symp. Japanse Geothnical Soc.*, pp44-49. In Japanese

Yoshimi, Y., Tokimatsu, K., Kaneko, O., and Makihara, Y.(1984), " Undrained cyclic shear strength of a dense Niigata sand, *Soil and Foundation*, 24, 4, pp131-145.