ESTIMATION OF STRONG-MOTIONS AT DOWN-HOLE SITES IN THE KASHIWAZAKI-KARIWA NUCLEAR POWER STATION BY RETRIEVING THE PEN-WRITING RECORDS FROM THE MAIN SHOCK OF THE 2007 NIIGATA-CHUETSU-OKI EARTHQUAKE

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ABSTRACT :

Two down-hole array strong-motion digital records on IC-memory cards at the Kashiwazaki-Kariwa Nuclear Power Station of Tokyo Electric Power Company during the main shock of the 2007 Niigata-Chuetsu-oki earthquake (Mj=6.8) were overwritten by succeeding aftershocks due to the less memory-capacity of the recording system. However, the monitoring pen-writing records were remained; therefore, we tried to retrieve the waveforms during the main shock by digitizing the pen-writing records using a CAD system and we prepared the report for estimating the strong-motions at some down-hole sites.

KEYWORDS: Niigata Chuetsu-oki earthquake, Kashiwazaki-Kariwa Nuclear Power Station, pen-writing records, digitization, vertical array strong-motion data

1. INTRODUCTION

During the Niigata Chuetsu-oki earthquake (M6.8) of July 16, 2007, a dense strong-motion observation system was operating at the Kashiwazaki-Kariwa Nuclear Power Station (KK-NPS) of Tokyo Electric Power Company (TEPCO). Damage to the important structures of KK-NPS was not recognized, but in the premises ground/road, inside of office buildings, water tanks, and others suffered heavy losses due to the strong shaking. The site located very near to the focal area; therefore, the strong-motion records are very important for understanding the behavior of the NPS during the strong shaking as well as for studying source complexity. Unfortunately, two down-hole array digital records from the main shock were overwritten by succeeding aftershocks due to the less memory capacity of the recording system. However, the peak acceleration data and the monitoring pen-writing records were remained on the sheets of paper, respectively. A digitization of strong-motion records from films or paper sheets is not curious still present, however, the problems are that the paper speed of the pen-writing records was very slow (1 mm/sec) and most traces were partly overloaded (clipped) due to high accelerations. Nevertheless the difficulties, these data will be very valuable to understand the input ground motion to the KK-NPS and its vicinity during the main shock, even if the retrieve is not perfect. This is a report on digitizing the pen-writing records and on the strong ground motions during the main shock at several depths.

2. SUMMARY OF THE PEN-WRITING RECORDS

The pen-writing records were basically used as a monitor for confirming the operation. Figure 1 shows the pen-writing records from the main shock. The lowest trace of Figure 1 is a time code. Table 1 shows the site by a circle showing that the pen-writing was connected with sensors. Figure 2 shows the schematic cross section of

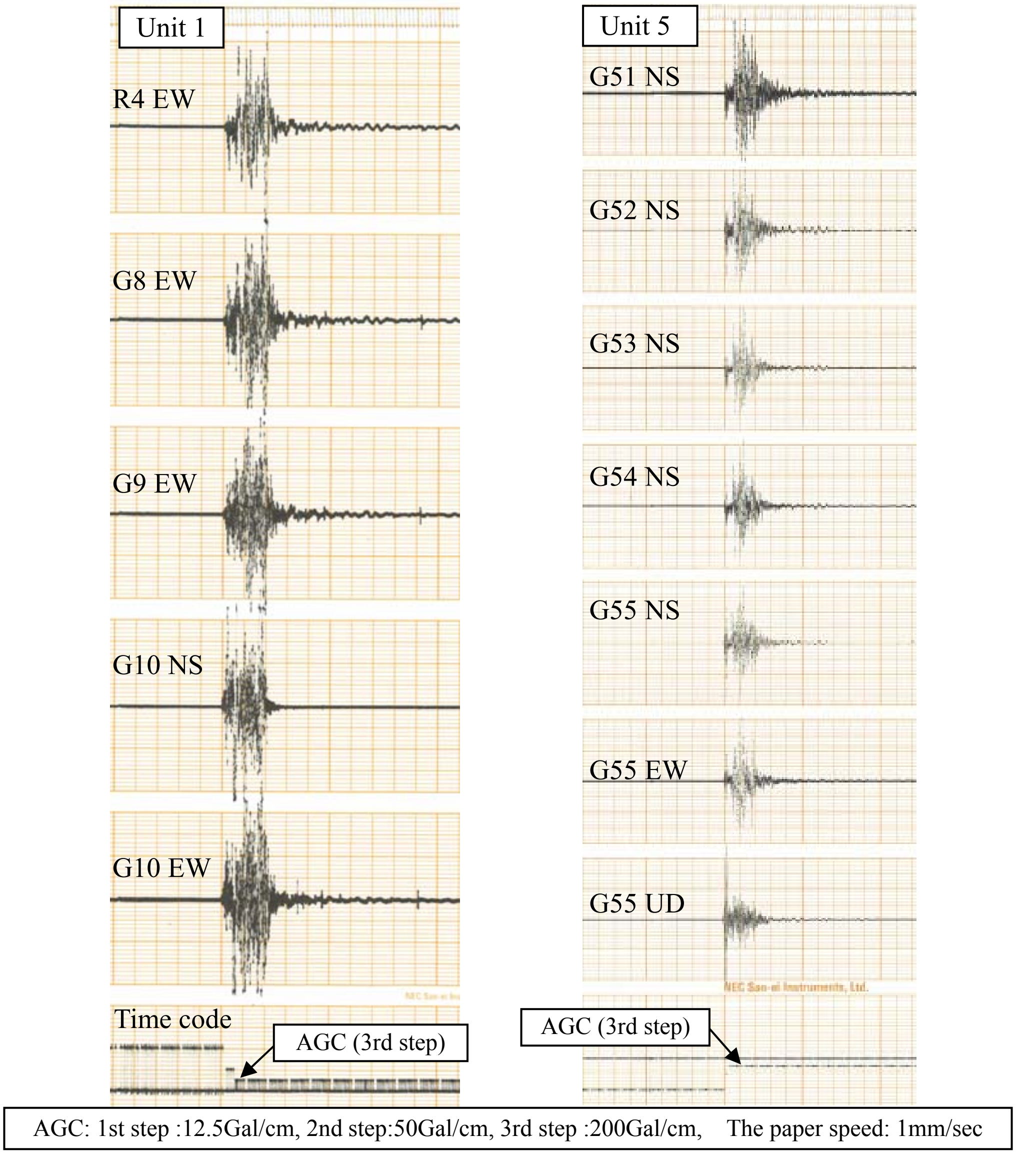
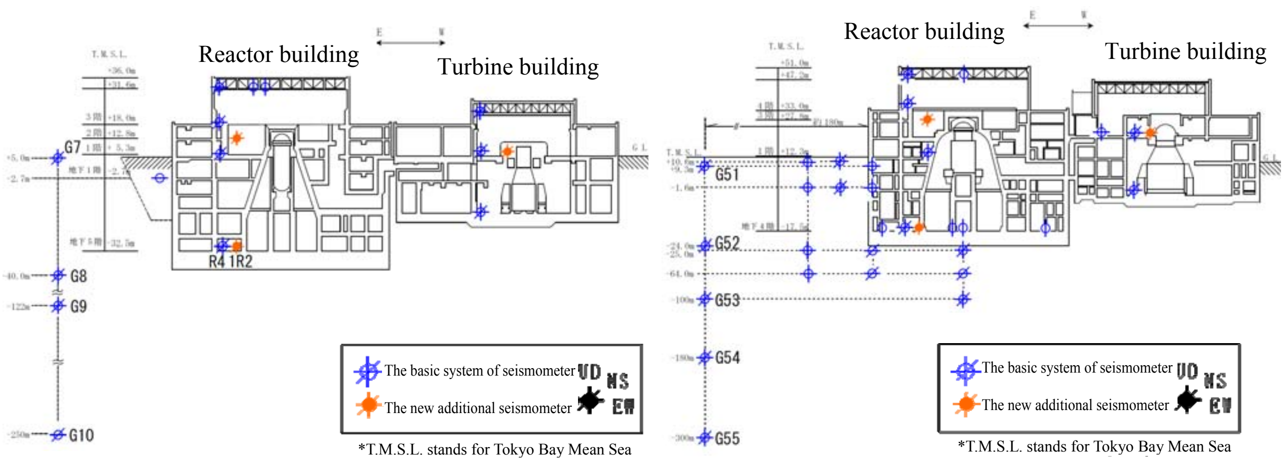


Fig.1. The monitoring pen-writing records of the Niigata Chuetsu-oki earthquake (M6.8) of July 16, 2007



(a)the section view of Unit 1 reactor and turbine building

(b)the section view of Unit 5 reactor and turbine building

Fig.2. Schematic cross sections of the Unit 1 and Unit 5 in the KK NPS and the location of sensors

Table1. Observation points of down-hole array and components connected with pen-writing

(a)Unit 1

site name	the pen writing NS	EW	UD	location of seismometer T.M.S.L(m)
R4	—	○	—	−32.5 (base mat)
G8	—	○	—	−40.0(down-hole)
G9	—	○	—	−122.0(down-hole)
G10	○	○	—	−250.0(down-hole)

(b)Unit 5

site name	the pen writing NS	EW	UD	location of seismometer T.M.S.L(m)
G51	○	—	—	+9.3(down-hole)
G52	○	—	—	−24.0(down-hole)
G53	○	—	—	−100.0(down-hole)
G54	○	—	—	−180.0(down-hole)
G55	○	○	○	−300.0(down-hole)

○: The component connected with the pen recorder

- : The component not connected with the pen recorder

the plant and the location of sensors connected with the pen writing recorder.

Because to cover the limitation of dynamic range of pen-writing system, an automatic gain control (AGC) of three steps of sensitivity is provided. The first step is the highest sensitivity of 12.5 Gal/cm, where Gal means 0.01 m/s/s. Once ground motion exceeds the level, the sensitivity of pen-recorder is altered to the second level (50 Gal/cm) and/or to the final one (200 Gal/cm). The altered lower sensitivity is kept during one event triggering. The clipping level of the lowest sensitivity is 400 Gal, but a margin permits a slightly higher accelerations. Even if the pen-writing record is digitized with sufficient accuracy, we are obliged to the resolution of DA converter with 12 bits. The AD conversion is 16 bits; therefore, the accuracy decrease from original digital data is inevitable.

3. PROCEDURE OF DIGITIZATION AND VERIFICATION OF THE ACCURACY

The pen-writing record was made an electronic picture file using a scanner and the coordinates of points were manually read using CAD system, by expanding the traces on the screen, especially, the time axis is elongated. Figure 3 shows the enlarged pen-writing records retrieved by a scanner. PN, PS, PE, and PW in the Figure mean plant-north, plant-south and so on, respectively. The plant direction is rotated about 19 degree from the true north to east clock wisely. The part of the shadow in Figure 3 is a part of AGC acting transiently in the first and second levels, and the part is excluded from the digitization. We digitized successive peaks and troughs by reading their coordinates using the CAD system. Next, those read coordinates of the waveforms are transferred to time and acceleration. Waveforms were finally re-sampled with an interval of 0.01 seconds by the cosine interpolation method. The cosine interpolation provides a new point (X, Y) by read points A(X1, Y1) and B(X2, Y2) using by the following expressions.

$$Y = 0.5(Y_2 - Y_1) + 0.5(Y_1 - Y_2) \times \cos(\pi \cdot \frac{X - X_1}{X_2 - X_1}) \quad (3.1)$$

To verify or to estimate the accuracy thus obtained digital waveforms, we compared them with the records retrieved near the site. Digital waveform (time history) data was obtained at the site 1R2, that is installed solitary at the base mat of the Unit 1 reactor building. The locations 1R2 and the site R4 (pen-writing record site) are very near each other (1R2 is located about 15m north from R4). Figure 4 shows the comparison of accelerograms of the digital data (1R2) and the digitized pen-writing record (R4) re-sampled by the cosine interpolation method. The digitized pen-writing record and the digital data match well except the clipped (overloaded) part. If the clipped point is only one, it is possible to use the printed peak acceleration data (PGA), that were remained by the other system, as the acceleration value of the clipped point. Assuming that there was the peak value in the mid-point of the clipped part, the waveform re-sampled again by cosine interpolation method is also shown by a dotted line in Figure 4. Figure 5 compares the Fourier spectrum amplitudes of waveforms shown in Figure 4. We could obtain satisfactory agreement except for shorter period than 0.15 sec. and longer period than 1 sec. Because we read only peak value, it is undoubtedly that there is a limit in the retrieving for short-period motion. Moreover, it is plausible that the influence of the resolution decrease in DA was negligible for long-period motion. The thickness of the line on the pen-writing corresponds to about 0.3

sec. and the resolution of digitization would be about 0.1 sec. by digitizing the center of line on the pen-writing trace, except the parts of very high frequency contents. We should note, however, that the accuracy is not always same for the other sites.

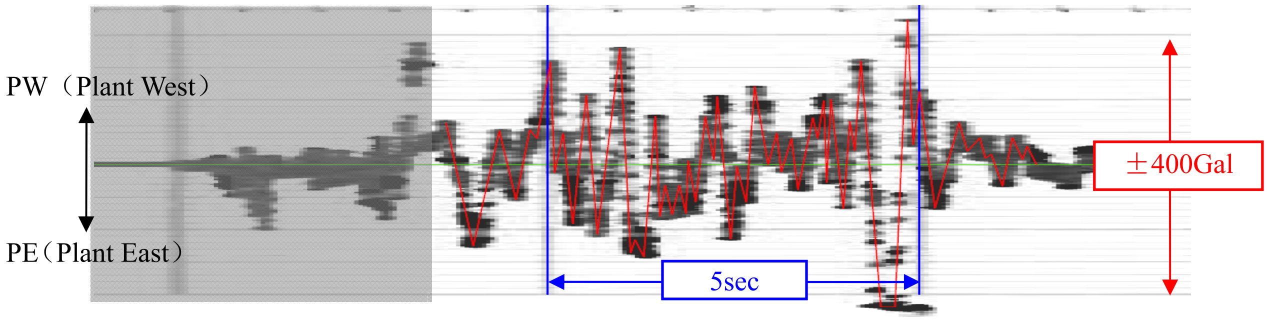


Fig.3. Comparison of the pen-writing records (black trace) and the waveform read (red trace) at R4 (EW component) of the main shock.

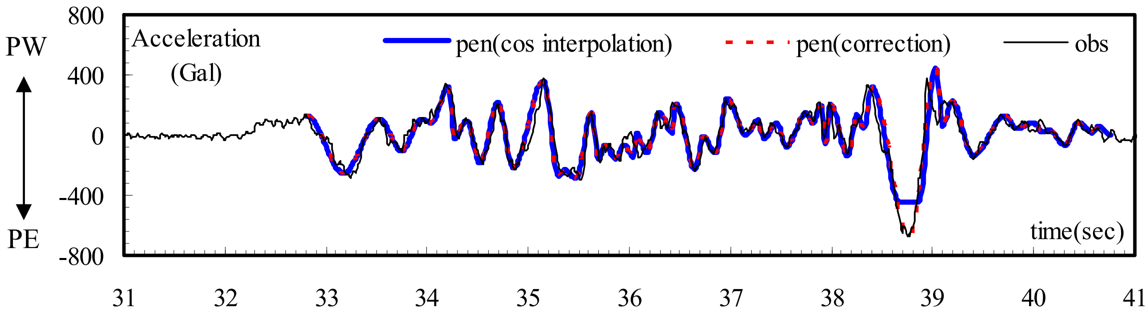


Fig.4. Comparison of the digital recording (1R2, black trace) with the digitized pen-writing record (R4, blue trace) and the digitized pen-writing record corrected using the peak acceleration (R4, red trace).

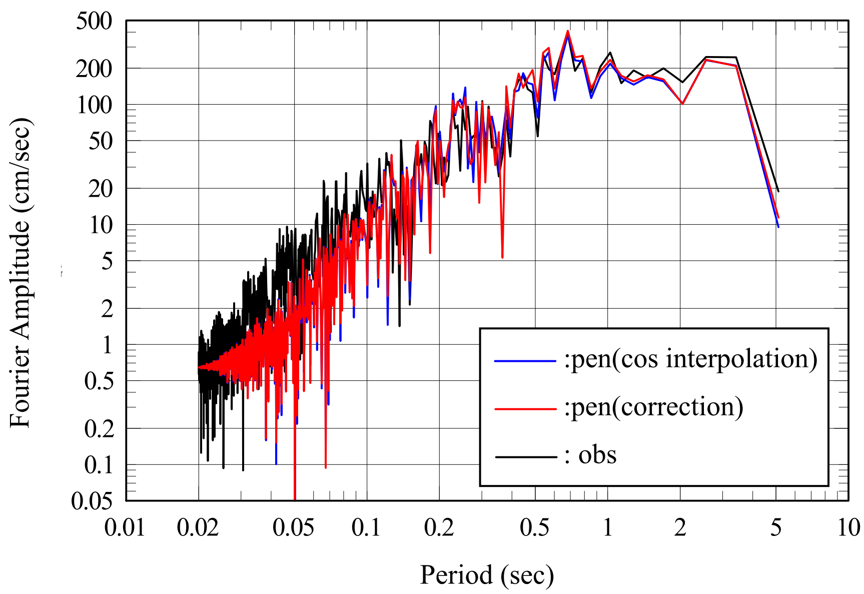


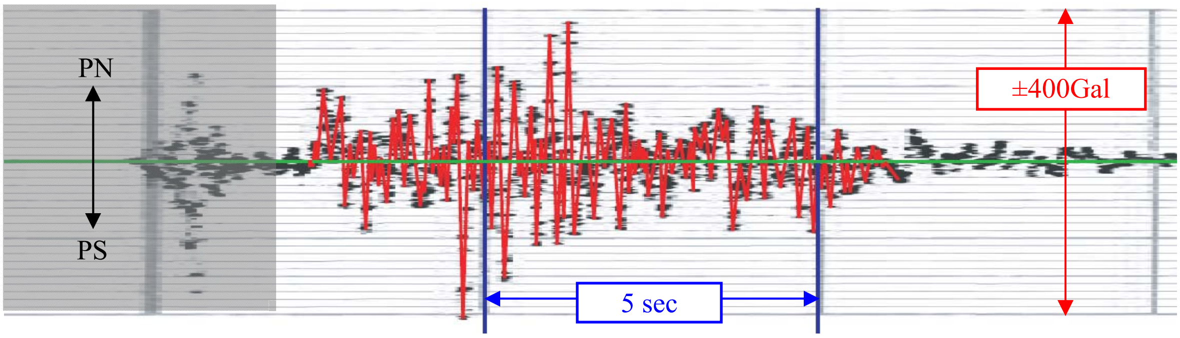
Fig.5. Comparison of Fourier spectrum amplitudes among the digital recording (1R2, black trace), the digitized pen-writing record (R4, blue trace) and the digitized pen-writing record corrected its peak acceleration (R4, red trace).

4. THE DIGITIZED PEN-WRITING RECORDS AT THE DOWN-HOLE SITES

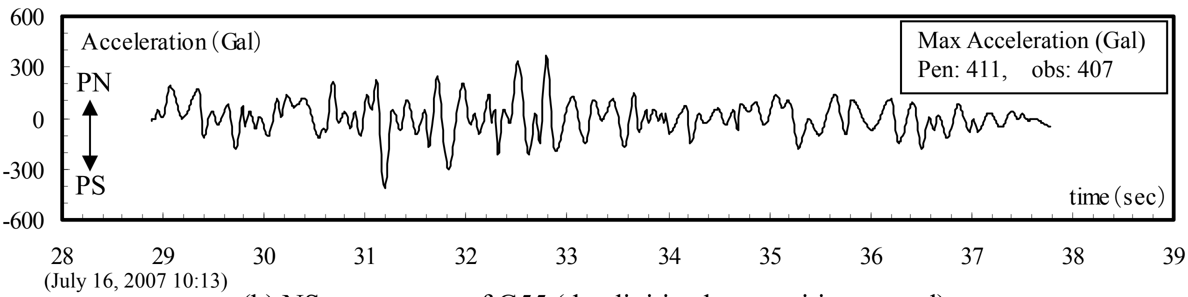
The other examples digitized by the same method are shown in Figures 6 and Figure 7 together with the peak acceleration of the main shock that were printed by the separate system. The digitized pen-writing records and estimated ground motions can be described as followings.

4.1 The down-hole sites near Unit 5

Figure 6 shows the digitized pen-writing record at down-hole sites near the Unit 5 reactor buildings. The short-period component is not so rich, therefore; it is comparatively easy to digitize. In addition, the clipped points would be nothing in the NS component and only one in the EW one of the site G55. The large acceleration is only found at early arrivals different from the waveforms of the Unit 1. A dominant pulse found in the latter half of EW component at the sites near the Unit 1 reactor buildings is obviously small at G55. A quite similar relation is found in the records from the main shock at the base mat of the Unit 1 and Unit 5 reactor buildings. Because of large numbers of the clipped points, we did not digitize the record at the site G51. A PGA from our digitization is quite similar to that of the printer data. In a case of the site G55, the PGA was 411 Gal, while it was 407 Gal on the printer retrieved by the other system.



(a) NS component of G55 (the pen-writing record)

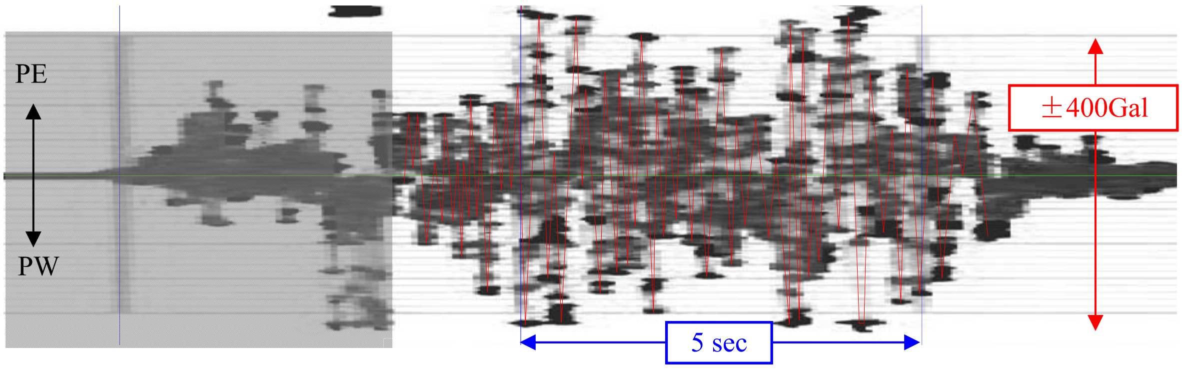


(b) NS component of G55 (the digitized pen-writing record)

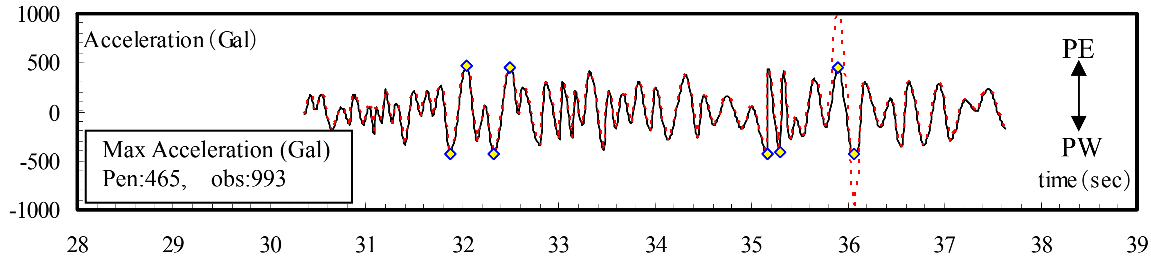
Fig.6. The digitized pen-writing record retrieved applying the cosine interpolation method at G55, the down-hole site near Unit 5.

4.2 The down-hole sites near Unit 1

Figure 7 shows the digitized pen-writing records at the down-hole (-250 m) site G10 near the Unit 1 reactor buildings. The strong ground motion near Unit 1 dominates short-period ground motion compared with those at the down-hole sites near the Unit 5. Therefore, reliability of digitization will be lower than that of down-hole sites near the Unit 5. Moreover, it is recognized that more than three parts are clipped at the sites G9 and G10. It is difficult to get a complete retrieving including the peak acceleration. On the other hand, reliability of digitization for the records at site G8 is much better than the former cases, because short period contents are less and clipped points seems only two parts.



(a) EW component of G10 (the pen-writing record)



(b) EW component of G10 (the digitized pen-writing record)

*red trace: the digitized pen-writing record corrected using the peak acceleration remained on a printer.
◇:Point presumed to be clipped due to high accelerations.

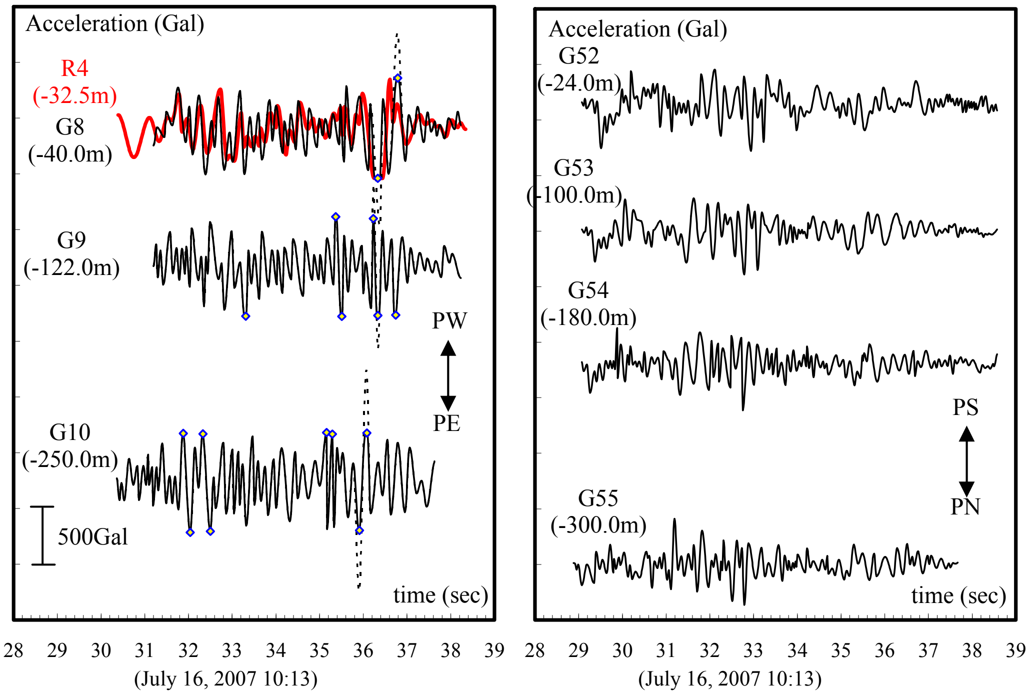
Fig.7 The digitized pen-writing record retrieved applying the cosine interpolation method at G10, the down-hole site near Unit 1.

4.3 Comparison of ground motion at depths

The digitized pen-writing records were retrieved by the cosine interpolation method and the clipped parts are presumed again by the cosine interpolation method including the peak acceleration data remained on a separate recording sheet. The relative timing is valid for all recorded channels at least they are on one sheet of records at 2 sites, respectively, and the absolute time is also available by reading the time code on the paper within an accuracy of about 0.1 sec., because of self time-adjusting by receiving the time signal from the radio station. Integrated above information, although available components are very limited, we made record sections of digitized down-hole array waveform as shown in Figure 8. Dotted lines shows the acceleration presumed with the aid of PGA on the recording sheet. Up-going pulses are clearly identified and large pulses at Unit 1 characterize the EW ground motions. On the other hand, NS components of Unit 5 dominate acceleration amplitudes in early arrivals and the later pulses have not significant amplitudes. The horizontal distance between G10 and G55 is very near only about 1.5 km and S-wave velocities of two sites are about 700~900 m/s at deepest points, that is almost identical. However the ground motions differ significantly each other, even at each deepest site that can be said as a base rock.

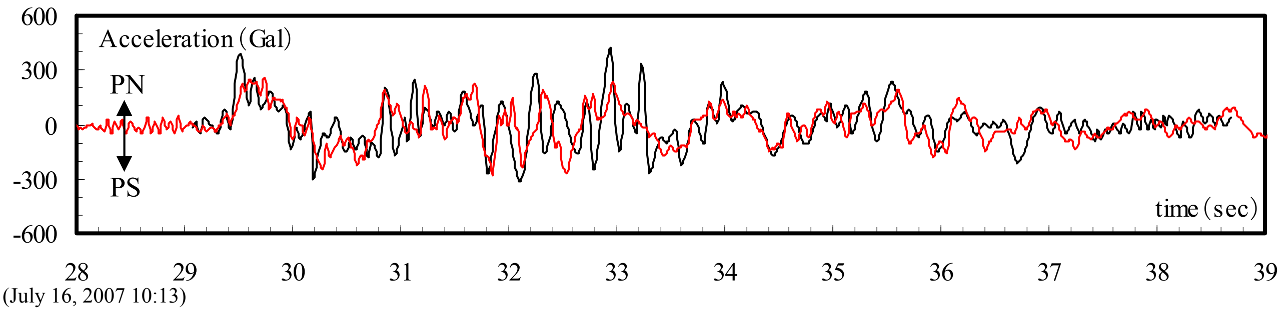
4.4 The comparison between the deconvolved ground motions at depths using the records on the base mat and digitized pen-writing records

Tokyo Electric Power Company (2008) published their estimates on the ground motion at depths during the main shock, deconvolving the observed waveforms at the base mat of each Unit and underground geotechnical data including non-linear effects. We compared our digitized waveforms with those postdicted ones by TEPCO as shown in Figure 9. We may say that both waveforms match well except for short period contents, nevertheless they are estimated by different methods, independently.

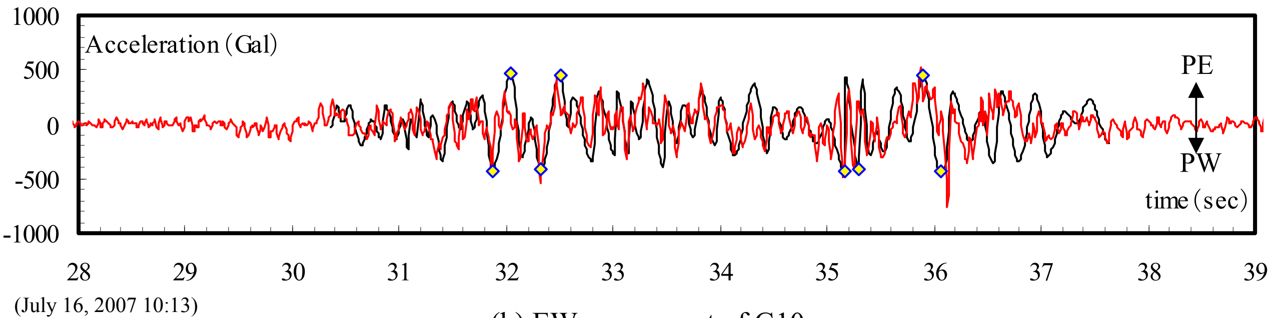


（a） the down-hole sites near Unit 1(EW component) （b） the down-hole sites near Unit 5(NS component)

Fig.8. The digitized pen-writing record presumed by the cosine interpolation method (Solid line) and the digitized pen-writing record presumed by the cosine interpolation method and the peak acceleration data remained (Dotted line). ◇:Point presumed to be clipped due to high accelerations.



(a) NS component of G53



(b) EW component of G10

Fig.9. The comparison of ground accelerations during the main shock at the down-hole sites of Unit 1 and Unit 5 between the digitized pen-writing records (black trace) and the simulation deconvolved using the base mat recordings (red trace) ◇: Point presumed to be clipped due to high accelerations.

5. CONCLUSIONS

We have tried to retrieve the waveforms at the down hole array sites in the KK-NPS of TEPCO during the Niigata Chuetsu-oki earthquake (M6.8) of July 16, 2007 that were overwritten by the followed aftershocks due to the less memory capacity of the recording system. Monitoring pen-writing records were the only record to retrieve waveform at depth. The problems were that the paper speed of the pen-writing records was too slow to follow the pen-movements and most traces were partly clipped due to high accelerations. The electric images of pen-writing records were possible to be enlarged linearly as well as individually for X and Y axes by a CAD system, so that we could retrieve the ground motions except the clipped portions. Recovery of data is incomplete; however, these digitized data will be very valuable when we try to understand the input motion to the KK-NPS and its vicinity during the main shock. Therefore, we were obliged to retrieve them incompletely. However, these digitized data will be very valuable when we try to understand the input motion to the KK-NPS and its vicinity during the main shock. The digitized pen-writing records were retrieved by the cosine interpolation method and the clipped parts are presumed again by the cosine interpolation method including the peak acceleration data remained on a separate recording sheet.
We compared our digitized waveforms with those postdicted ones by TEPCO (2008). We may say that both waveforms match well except for short period contents; nevertheless they are estimated by quite different methods, independently.

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