CHARACTERISTICS OF STRONG MOTION RECORDS IN KASHIWAZAKI-KARIWA NUCLEAR POWER STATION DURING THE NIIGATAKEN CHUETSU-OKI EARTHQUAKE IN 2007

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ABSTRACT :

THE NIIGATAKEN CHUETSU-OKI EARTHQUAKE OF M6.8 OCCURRED AT 16 KM FROM THE KASHIWAZAKI-KARIWA NUCLEAR POWER STATION ON JULY 16, 2007. ALL REACTORS IN OPERATION AUTOMATICALLY SHUTDOWN AS DESIGND AND THE STRONG MOTION DURING THE QUAKE WERE OBSERVED AT MANY POINTS IN THE SITE. THE MAXIMUM ACCELERATION OBSERVED ON THE BASE MAT OF REACTOR BUILDING WAS 680 CM/S^2 AT UNIT 1. THE PEAK ACCELERATION VALUES IN EAST-WEST COMPONENTS WERE LARGER THAN THAT OF NORTH-SOUTH COMPONENTS AND THE PEAK ACCELERATION VALUES IN SOUTH SIDE OF THE SITE WERE LARGER THAN THAT IN NORTH SIDE. THE WAVEFORMS HAVE SHORT DURATION ABOUT 10 SECONDS AND THREE SIGNIFICANT PULSES ARE IDENTIFIED IN THE WAVEFORM. THESE PULSES ARE ASSUMED TO ASPERITY PULSES. THE THIRD PULSE FROM THE ASPERITY LOCATED THE WEST OF THE SITE AFFECTED THE PEAK ACCELERATION CHARACTERISTICS. THE THIRD PULSE WAS AMPLIFIED BY THICK NEOGENE STRATUM AND FOLD GROUND STRUCTURE IN THE SITE. IT SEEMS TO BE THAT THE HIGH ACCELERATION AND SPATIAL VARIATION OF THE OBSERVED RECORDS IN THE SITE ARE DUE TO BOTH EFFECTS OF SEISMIC SOURCE AND GROUND CONDITION.

KEYWORDS: **THE NIIGATAKEN CHUETSU-OKI EARTHQUAKE, NUCLEAR POWER STATION, NEAR SOURCE STRONG MOTION, ASPERITY PULSE, IRREGULAR GROUND STRUCTURE.**

1. INTRODUCTION

The Niigataken Chuetsu-oki Earthquake in 2007 occurred in very short distance from the Kashiwazaki-Kariwa Nuclear Power Station (KK-NPS) of the Tokyo Electric Power Company (TEPCO). The magnitude of the event determined by Japan Meteorological Agency is 6.8 and the distance between epicenter and the site was about 16 km. The locations of epicenter and the site are shown in Figure 1. The source mechanism of the event assumed to be a reverse fault with east dip fault plane. KK-NPS is located almost over the source fault plane. There are seven reactor units in the station. Unit 3, 4 and 7 in operation and unit 2 under start up operation automatically shutdown as designed. Unit 1, 5 and 6 were not in operation for annual outage when the earthquake occurred. Some damages were found in facilities with low safety significance but the important equipment for safety of reactor was not damaged and there was no environmental impact. The strong motion records during the quake were retrieved at all reactor buildings, turbine buildings and several ground observation points. Maximum acceleration value on the base mat of reactor building was 680 cm/s^2 observed at unit 1. Maximum acceleration value at ground level was 1,223 cm/s^2 observed on the base mat of small building for earthquake observation. Although the acceleration of observed strong motion exceeded the design based seismic motion of KK-NPS, the function to keep the safety of reactor acted properly and important structures and facilities for nuclear safety had almost no damage. It is important to study the characteristics observed records and to realize the reason why such high acceleration was observed for improvement of seismic safety of not only KK-NPS but also nuclear power stations all over the world.

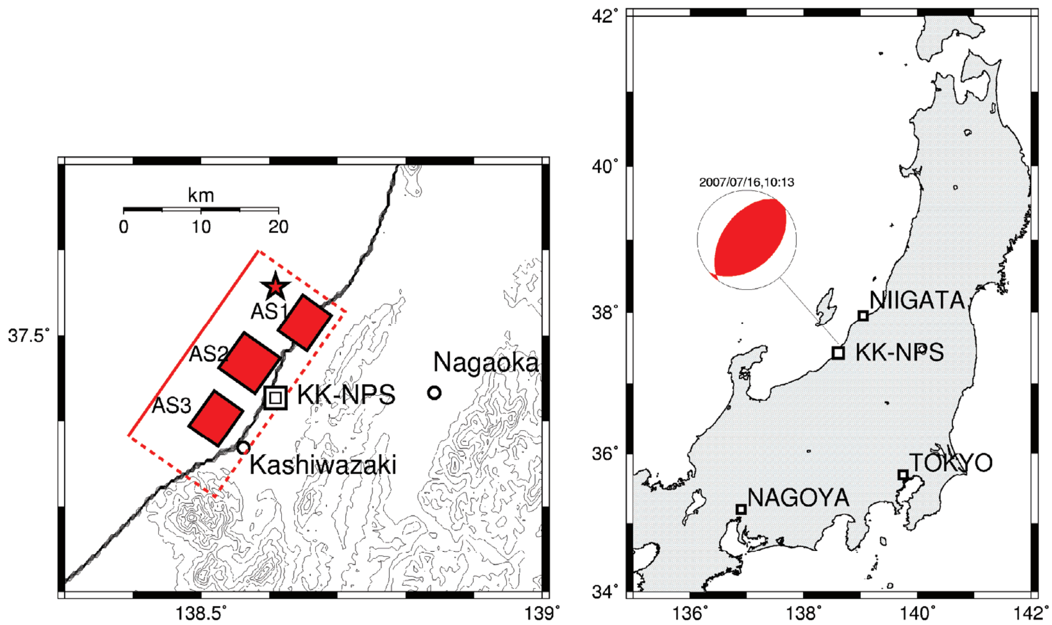


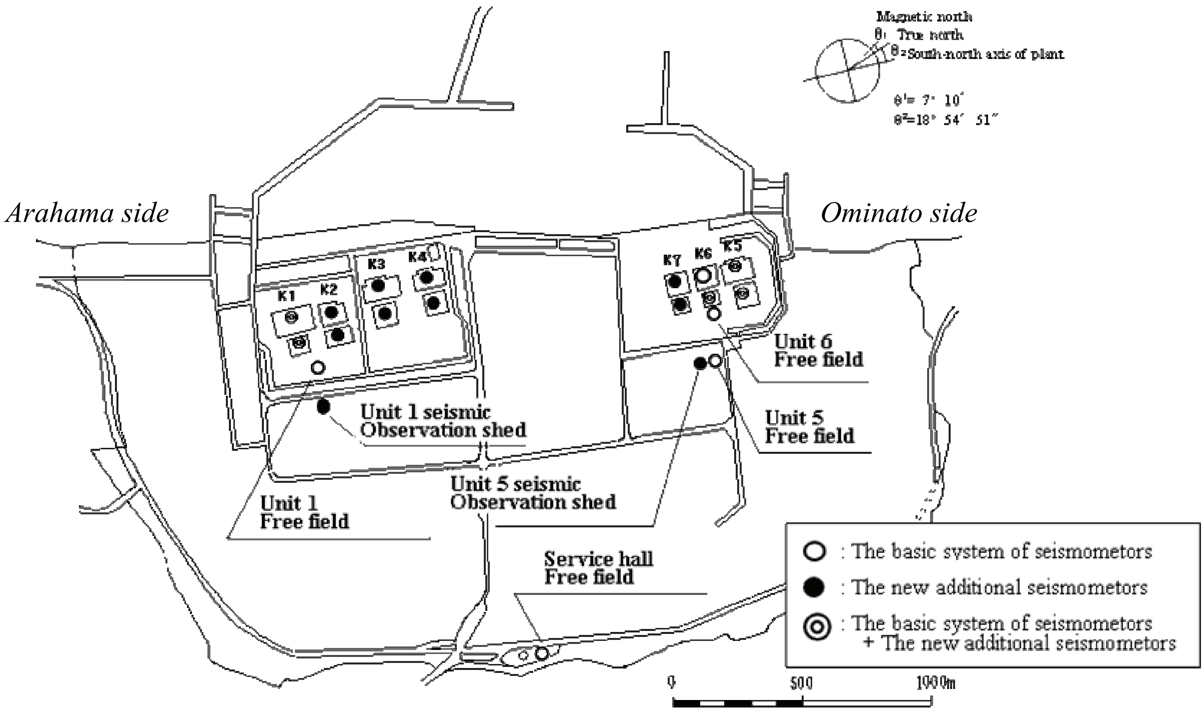
Figure 1 Location of Kashiwazaki-Kariwa Nuclear Power Station and the Niigataken Chuesu-oki earthquake. The location of KK-NPS and fault mechanism determined by National Research Institute for Earth Science and Disaster Prevention are shown in Right Figure. Left figure shows the site location and the characterized source model of the event. Star shows epicenter determined by Japan meteorological agency. Large and small rectangles show faults plane and asperities estimated by inversion analysis [TEPCO (2008)].

2. OBSERBATION SYSTEM AND RECORDS OF THE EVENT

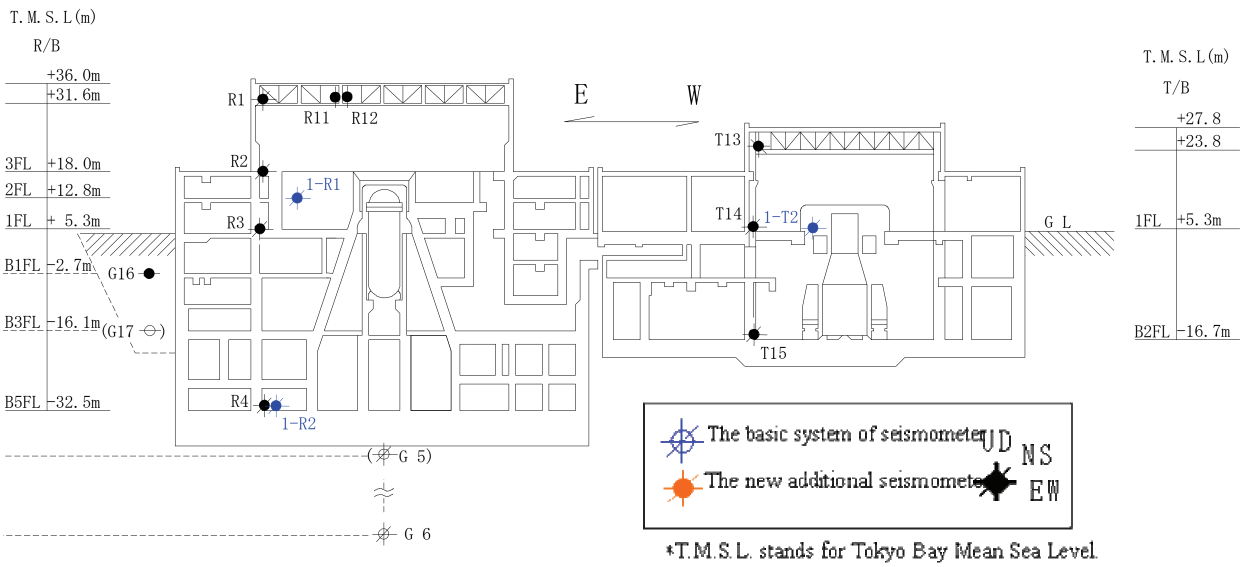
In the KK-NPS, total 97 acceleration seismometers are installed in reactor buildings, turbine buildings and the ground for recording the behavior during the earthquakes. The locations of observation points are shown in Figure 2. Upper figure shows location of observation points in KK-NPS and lower figure shows the observation points in unit-1 buildings as an example of sensor location in buildings. The north–south axis of plant coordinate is rotated about 19 degrees from north to east clockwise. Sensors in the site are adjusted to the plant coordinate.

The observation systems are divided into the original system and new additional sensors. The Original system was installed before 2007 and composed of vertical array in ground and sensors in buildings of unit 1, 5, and Service-hall (PR-hall). Velocity feedback type accelerometers are used for original system. Observation range of original system is 1,000 cm/s^2 full scale and its frequency response is flat between 0.05 and 20 Hz. The new additional sensors were installed in buildings of all units and observation shed in March 2007. In reactor and turbine buildings, seismometers are installed on basement floor and some upper floors. Displacement feedback type accelerometers are used for new sensors. Observation range of new sensor is 2,000 cm/s^2 full scale and its frequency response is flat from DC to 20 Hz. The time correction of original system is automatically executed using time signal of public broadcast but new sensors have no automatic time correction system.

The digital data of the main shock were retrieved at the observed points of the new additional sensors and Service-hall vertical array but the digital data at 63 points of original system at unit 1 and 5 were lost by overwriting unfortunately. We can use some information to estimate the lost data. The peak acceleration values were recorded for all observation points and the pen-writing monitoring records were left for several observation points of original system at unit 1 and 5. From these clues, we can suppose some characteristics of lost digital data.



(a) Plan of the KK-NPS



(b) Section of the reactor and the turbine buildings of Unit-1

Figure 2 Location of seismic observation points in the Kashiwazaki-Kariwa NPS. Top figure shows the plan view of the site and indicates the observation point location. Bottom figure shows the section view of unit-1 reactor and turbine building and indicates the sensor location as an example of sensor location in buildings.

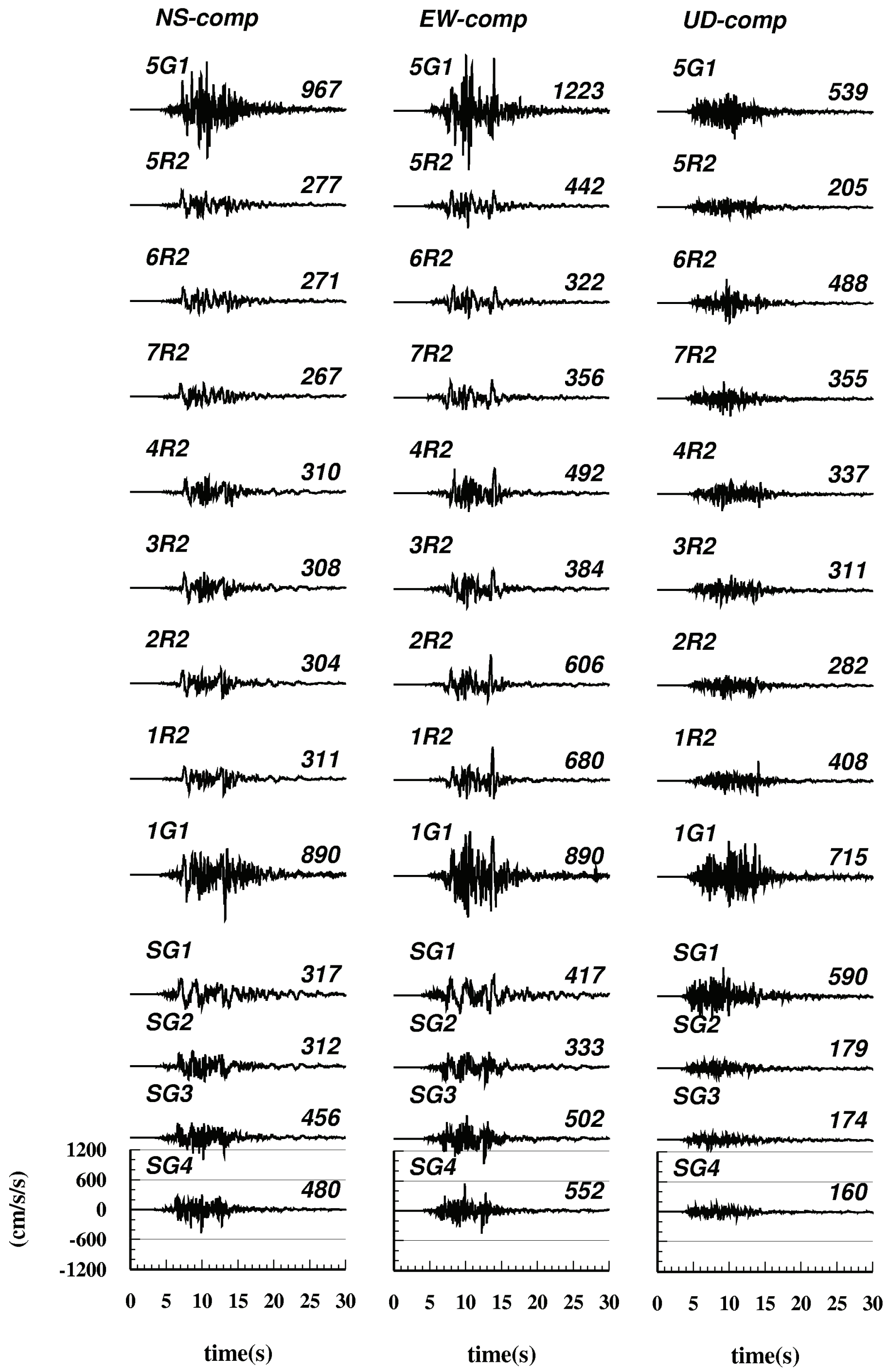


Figure 3 Acceleration waveforms observed during the Niigataken Chuetsu-oki earthquake. Observation points from SG1 to SG4 are vertical array of Service-hall. Elevation of SG1 is 65.1m and depth is 2.4 m from ground level. Depths of SG2, SG3 and SG4 are 50.8 m, 99.4 m and 250 m, respectively. 1G1 is in observation shed of Arahama side. Observation points from 1R2 to 7R2 are on the base mat of reactor buildings. Elevation of 1R2, 2R2, 3R2 and 4R2 are -32.5 m. Elevation of 5R2 is -17.5 m. Elevation of 6R2 and 7R2 are -8.2 m. 5G1 is in observation shed of Ominato side. The figures written in right side of traces are peak acceleration values.

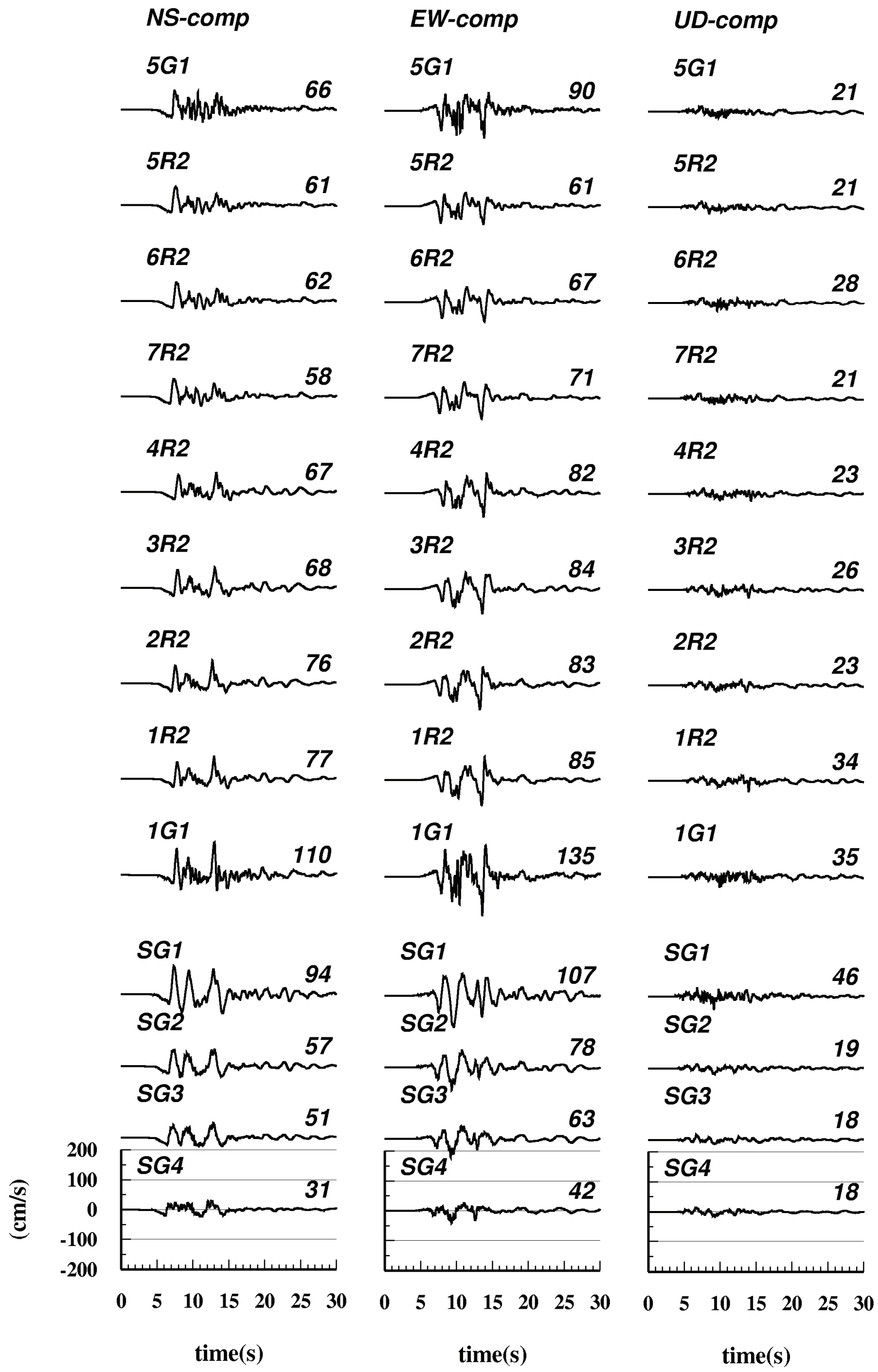


Figure 4 Velocity waveforms integrated from observed acceleration waveforms. In integration, the lower-frequency components than 0.02 Hz are cut-off by cosine-tapered filter in frequency domain. The figures written in right side of traces are peak velocity values.

3. STORONG MOTION CHERACTERISTICS

3.1. Waveform Characteristics

The observed acceleration waveforms are shown in Figure 3. The observation shed 1G1 and 5G1 show very high acceleration about or over 1,000 cm/s^2. 1G1 and 5G1 are considered ground surface level. The maximum peak acceleration at base mat of reactor buildings is 680 cm/s^2 observed in east-west component of unit 1. The records on basement of reactor buildings show low acceleration compared to those at ground surface level because of effects of embedment of large structure and soil-structure interaction. These acceleration values are very high though those were observed on the base mat of embedded large building. The peak accelerations of unit 1, 2, 3 and 4 in Arahama side (the southern part of the site) are larger than those of unit 5, 6 and 7 in Ominato side (the northern part of the site). The peak accelerations of east-west components were larger than that of north-south components. Service-hall vertical array is composed of SG1, SG2, SG3 and SG4. Acceleration at SG1 is smaller than that of deeper observation points and apparent period of waveform at SG1 is longer than that of other observation points. These characteristics may be the results of non-linear response of sandy stratum. The observed acceleration waveforms show short duration about 10 seconds and have three significant pulses. Third pulse that observed after about 7 seconds from first pulse strongly influences the characteristics of peak acceleration variation.

The velocity waveforms integrated from acceleration records are shown in Figure 4. The three pulses that shown in acceleration traces in Figure 3 are more clearly but difference of peak values are lesser than that of acceleration. Peak velocity values in Service-hall vertical array show amplification from SG4 to SG1 in different with peak acceleration value. The third pulse observed in Arahama side is sharper than that of Ominato side. The velocity loci of the records are shown in Figure 5. The time-windows for drawing locus are selected as corresponding to the time of three pulses. First pulse is corresponding to first S-wave arrival and its main-axis of vibration directs to the north that correspond to epicenter direction. Vibration directions of second pulses are turn from the North to the West. The loci of third pulses are very complex and the characteristics in Arahama side are different from those of Ominato side.

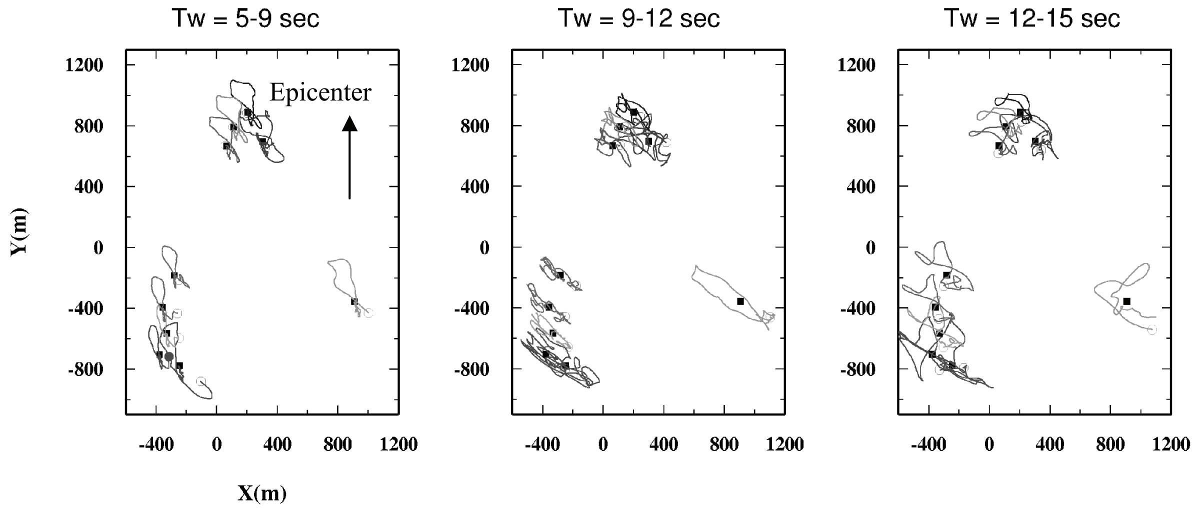


Figure 5 Velocity loci of observed records. X-axis and Y-axis indicate the east-west axis and the north-south axis, respectively. The times windows for drawing the loci are selected for including three significant pulses.

3.2. Propagation directions of three pulses in the site

The apparent propagation directions of three pulses are investigated by semblance analysis [Neidell and Taner (1971)]. For semblance analysis, records of seven reactors (1R2, 2R2, 3R2, 4R2, 5R2, 6R2 and 7R2), two observation sheds (1G1 and 5G1) and Service-hall (SG3). About Service-hall, we select SG3 because the data of ground surface point (SG1) show non-linear response and elevation of SG3 is near to other data points. Since the time information of the new additional sensors is not accurate, we have performed time correction of the records. Tanaka et al. (2008) have reproduced several original system data at unit 1 and 5 from pen-writing records. The time of new additional sensor of unit 1 and 5 were adjusted by the reproduced data. In addition, the time of unit 2, 3, 4, 6, and 7 were adjusted in according to the epicenter distance under assuming the P-wave velocity of 4.2 km/s that calculated from reproduced data of unit 1 and 5. The results of semblance analysis using velocity waveforms of the east-west components are shown in Figure 6. The window length of the analysis was 2 seconds. In analysis window from 2 to 4 seconds, the first pulse is contained in this window. The wave propagates from the north with apparent velocity of about 3.4km/s. In next window including second pulse, the wave propagates from northwest with apparent velocity of about 2 km/s. In the window including significant third pulse, wave propagates from the west with apparent velocity of 5.6 km/s. The high apparent velocity indicates that the incident angle to the site is near to vertical. The propagation direction and apparent velocity in each window show that the three pulses propagate from the corresponding asperities shown in Figure 1.

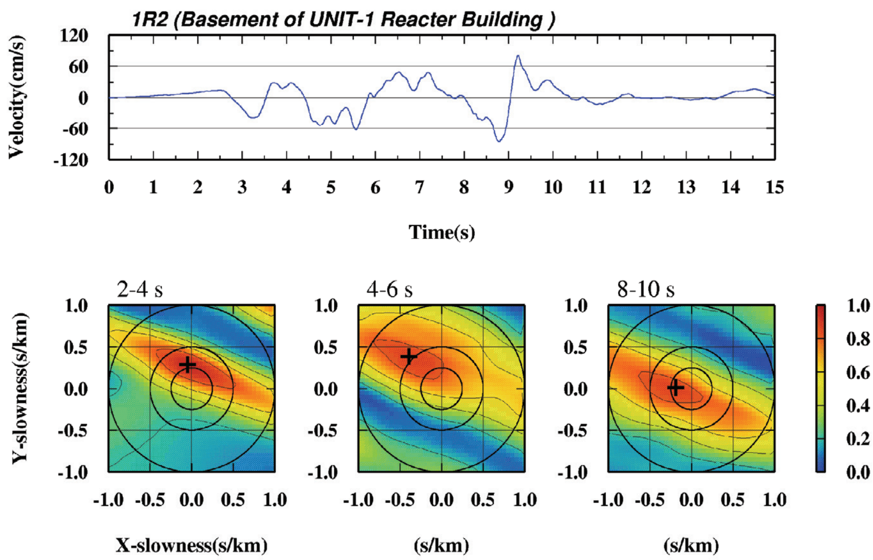


Figure 6 Results of semblance analysis for east-west components of velocity waveforms. Upper waveform shows the velocity waveforms at 1R2. Lower figures show the result of semblance analysis for three time windows. Results of semblance analysis are shown by contour map in slowness plane. Crosser indicate semblance peak point.

3.3. Spectral Ratios of the record of Unit 1 to that of Unit 5

It seems to be that the difference of the records in Arahama side and those in Ominato side is mainly from difference of third pulse characteristics. The running Fourier spectral ratios of 1R2 to 5R2 are shown in Figure 7. This figure shows the Fourier spectral ratio for moving window analysis. The window length was 5 second. Fourier spectra were calculated using FFT and were smoothed using Parzen windows of 0.1 Hz. The ratios vary in accordance with the time window and frequency. In the time window including the third pulse, the ratios are over 2 in wide frequency range especially in east-west component. Figure 7 shows that amplification characteristics of third pulse in the KK-NPS site are different from those of first and second pulses.

If the difference of amplification between 1R2 and 5R2 comes from the difference of local ground condition, the ratios should be almost a constant value without depending on the incident direction of the seismic waves. The phenomena that the spectral ratio show different value with depending on incident direction of the wave is assumed to an effect of complex ground structure. The geology of the Chuetsu area where KK-NPS site located is characterized by thick Neogene sediment and fold structure. The unit 1 located on the syncline and unit 5 located on the anticline [TEPCO (2008)]. We are studying the modeling of sub-surface structure of the site and numerical simulation to evaluate the effects of complex structure, now.

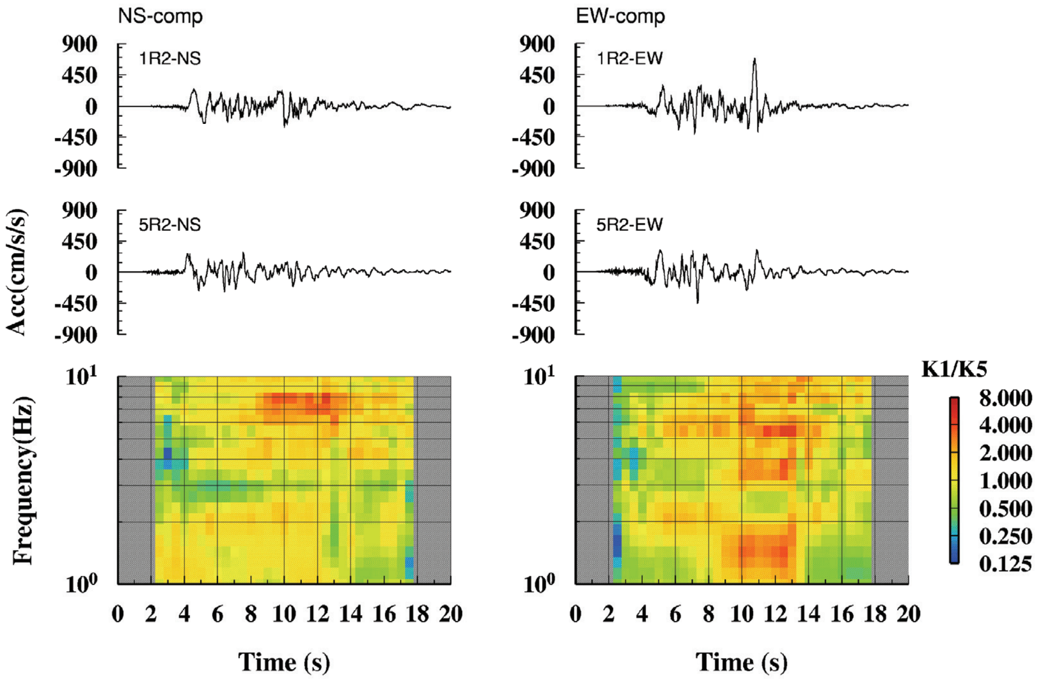


Figure 7 Running Fourier spectral ratios of 1R2 to 5R2. Left figure shows the result of north-south component and right figure shows the result of east-west component. Spectral ratios are shown by color contour maps.

5. CONCLUSION REMARKS

The characteristics of strong motion observed KK-NPS during the Niigataken Chuetsu-oki earthquake was affected by asperity pulses and complex amplification of the deep and fold sediment structure. We are on the way of detailed investigation of near source ground motion, now. We continue to study about the seismic source and the ground conditions and the results will contribute to improvement of seismic safety of nuclear power plants.

The observation records in KK-NPS during the 2007 Niigataken Chuetsu-oki Earthquake were published through the Association for Earthquake Disaster Prevention (AEDP). If you hope to get the digital data, please access web page of AEDP (http://www.aedp-jp.com/).

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