



INTERPRETATION OF EWING SEISMOGRAM OF THE 1923 KANTO, JAPAN EARTHQUAKE AT TOKYO

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Abstract

The 1923 Kanto, Japan earthquake caused tremendous disaster in Tokyo. For seismic hazard and risk assessment of Tokyo, it is important to understand ground motion of the Kanto earthquake. The strong ground motion of the Kanto earthquake was recorded at the University of Tokyo at Hongo, Tokyo with an Imamura seismograph and a Ewing seismograph. The Imamura seismogram was saturated intensely by severe collision of the damper plate against the oil tank wall. Yokota et al. (1989) made an extensive effort to reconstruct the seismogram. It seems, however, difficult to estimate the accurate ground motion from this record because of its very excessive clipping.

The Ewing seismogram was also not complete but off-scaled from the recording disk. Nasu and his colleagues (1973) digitized horizontal components of the record, and restored the off-scale parts. The estimated ground motion exhibits almost harmonic motion with a period of about 13 sec. Since the natural period of the pendulum was reported to be 6 sec, it often has been thought that the instrument must have malfunctioned and registered the peculiar harmonic motion (Takeo and Kanamori, 1997). Although the work by Nasu and his colleagues (1973) is appreciated as an attempt to reveal the ground motion of the Kanto earthquake, their description about the interpretation of the seismogram was not in detail. In this paper, we reexamine the characteristics of the Ewing seismograph and the seismogram of the Kanto earthquake to discuss the ground motion at Tokyo.

Nasu (1971) reported that the natural period of the pendulum, the damping factor and the revolving speed of the recording disk were 6.0 sec, 4.5% and 120 sec/round, respectively. Comparison of the seismograms by the Ewing seismograph with those by other seismographs at the same location supports the validity of the constants reported by Nasu (1971), and shows that the effects of the solid friction of the pendulum suggested by Takeo and Kanamori (1992) may not be significant for large ground motion.

The Ewing seismogram of the Kanto earthquake at Tokyo was digitized and interpreted. The seismogram consists of four series of the traces which are lines of discontinuity due to scale-out of the indicator of the seismograph. Considering the different arm length curvatures in traces of two horizontal and one vertical components, the three component traces are distinguished from four series of the traces. The tentative results of the interpreted horizontal record show the maximum amplitudes of about 20 cm with period of 13 sec and of about 40 cm with 7 sec for SW-NE and SE-NW components, respectively. The interpreted record of the Ewing seismogram seems to be consistent with the saturated Imamura seismogram at the same location. To reveal the ground motion of the Kanto earthquake at Tokyo more quantitatively, further investigation such as restoration of the off-scale parts and the instrumental correction should be necessary.

Keywords: Strong motion; Ewing seismogram; 1923 Kanto earthquake; Tokyo



1. Introduction

The 1923 Kanto, Japan earthquake caused tremendous disaster in Tokyo. For seismic hazard and risk assessment of Tokyo, it is important to understand ground motion of the Kanto earthquake. The strong ground motion of the Kanto earthquake was recorded at the University of Tokyo at Hongo, Tokyo with an Imamura seismograph and a Ewing seismograph, respectively [1]. The Imamura seismograph was saturated intensely by severe collision of the damper plate against the oil tank wall. Yokota et al. [2] made an extensive effort to reconstruct the seismogram. It seems, however, difficult to estimate the accurate ground motion from this record because of its very excessive clipping with two completely clipped portions [3].

The Ewing seismograph was also not complete but off-scaled from the recording disk [1]. Nasu and his colleagues digitized horizontal components of the record, and restored the off-scale parts by a parabola curve to estimate the ground motion [4-7]. The estimated ground motion exhibits almost harmonic motion with a period of about 13 sec. Since the natural period of the pendulum was reported to be 6 sec, it often has been thought that the instrument must have malfunctioned and registered the peculiar harmonic motion [8].

Although the work by Nasu and his colleagues [4-7] is appreciated as an attempt to reveal the ground motion of the Kanto earthquake, their description about the interpretation of the seismogram was not in detail. In addition, available information on the Ewing seismograph is few. This makes reliability of their estimated ground motion unclear. In this paper, we reexamine the characteristics of the Ewing seismograph and the seismogram of the Kanto earthquake to discuss the ground motion at Tokyo.

2. Ewing Seismograph

The Ewing seismograph was developed in 1881 and recorded the first ground motion record as a function of time [9]. Figure 1 shows an illustration of the seismograph installed at the Tokyo Central Meteorological Observatory [10]. The seismograph consists of three pendulums for two horizontal and one vertical components. The relative motion of the pendulum bob was recorded on a revolving circular paper as shown in Fig. 2 [1]. At the time of the 1923 Kanto earthquake, the Ewing seismograph at the University of Tokyo was not used for the routine observation, but maintained as an exhibit instrument. There are some notes about the turn speed written on the recording paper [11]. The time for one round was written as 59 sec, 40 sec, 40 sec, 121 sec, and 95 sec on the records on September, 1916, April, 1922, May, 1922, February, 1923, and September, 1924, respectively. Nasu checked the characteristics of the seismograph on May, 1931 [12] and reported that the time for one round, the natural period and the damping factor of the pendulum were 120 sec, 6.0 sec and 4.5%, respectively [4]. Since no other report is available on the characteristics of the seismograph, the values reported by Nasu [4] are used in this study.

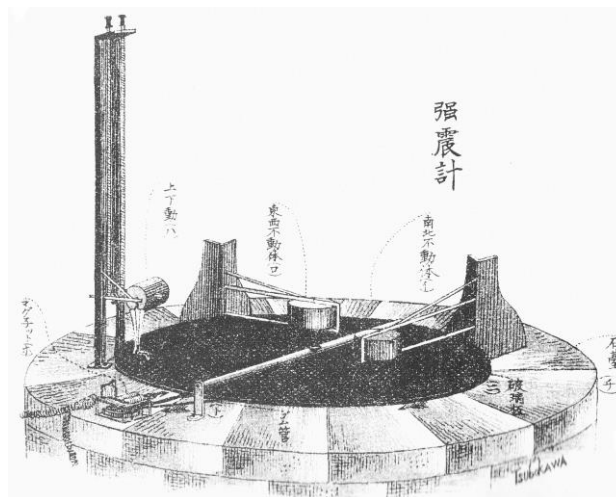


Fig. 1 – Appearance of Ewing seismograph (after Tsubokawa [10])

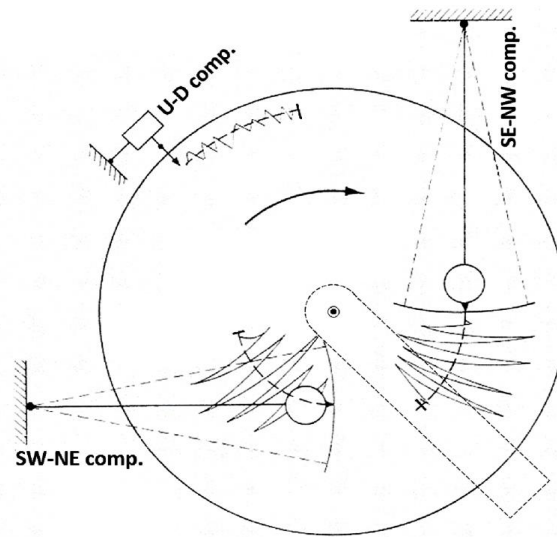


Fig. 2 – Schematic diagram of Ewing seismograph (modified from Nasu [1])

The Ewing seismograph registered a record of a large aftershock (M7.3) of the Kanto earthquake on January 15, 1924 [4]. This earthquake was recorded by another strong-motion seismograph at the same location. The natural period of the strong-motion seismograph was about 4 sec [13] which is similar to that of the Ewing seismograph. Figure 3 shows a comparison of the records registered by the Ewing seismograph (black line) and by the strong-motion seismograph (red line). Intervals between the minute time marks suggest that the strong-motion seismograph produced irregular paper speed after the S-wave arrival and then the paper speed came back to normal. This may cause inconsistency of the both record at a nearby part of the onset of the S-wave. At the later part, however, both records seem to be consistent. This supports the validity of the constants of the Ewing seismograph reported by Nasu [4].

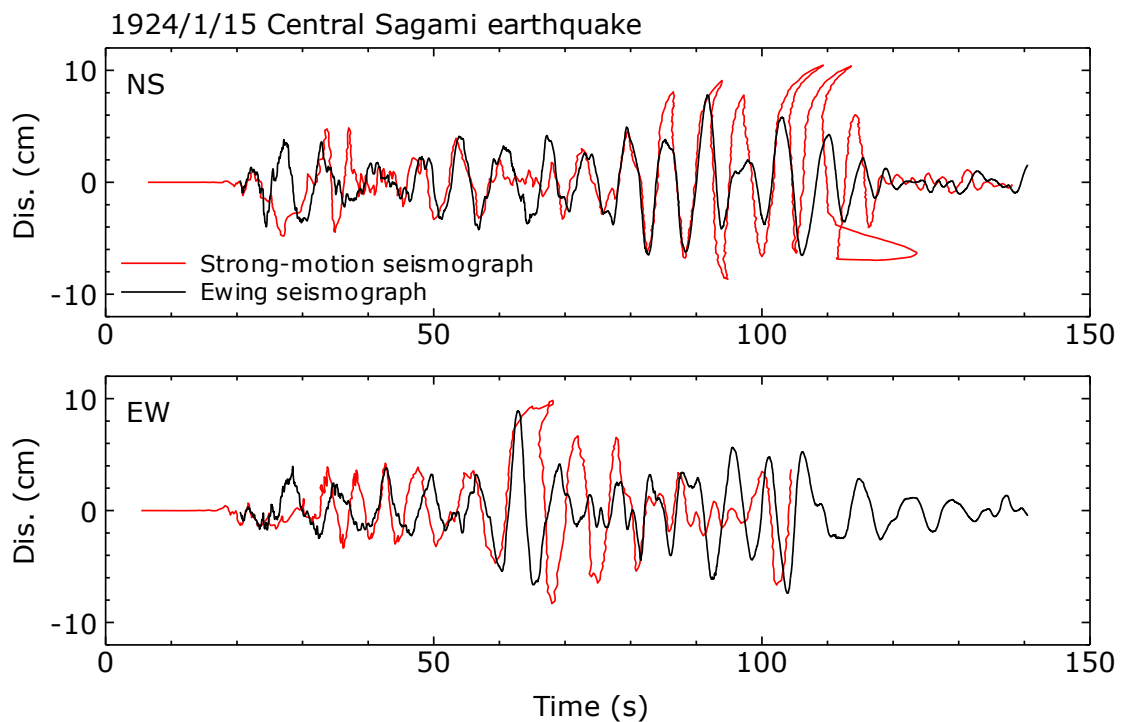


Fig. 3 – Comparison of records observed by Ewing seismograph and by strong-motion seismograph



Takeo and Kanamori [14] suggested the existence of large solid friction of the Ewing seismograph and its effect to the instrumental response. Information about the solid friction, however, is not available. To check the solid friction of the seismograph, we compare the records by the Ewing seismograph and those by the other seismographs at the same location which were digitized and processed by Tanaka et al. [15]. The comparison was made for four earthquakes occurred in September, 1916 to June, 1931. These earthquakes were local ones with M of 6.2 to 6.9 and hypocentral distance of about 100 to 200 km. Figure 4 shows the comparison of the observed Ewing record with the computed Ewing record from Omori seismograph during the earthquake of July 27, 1929. When the solid friction is ignored, the computed record (dotted red line) shows sinusoidal motion with 6 sec by resonance of the pendulum and differs from the observed one (black solid line). When the solid friction is set at 2.5 cm, the computed record (red solid line) becomes similar to the observed one. From the comparison for the records of four earthquakes, the solid friction of the Ewing seismograph is roughly estimated to be 1 to 3 cm. This value is not as large as one which was suggested by Takeo and Kanamori [14]. The effects of the solid friction may not be significant for large ground motion.

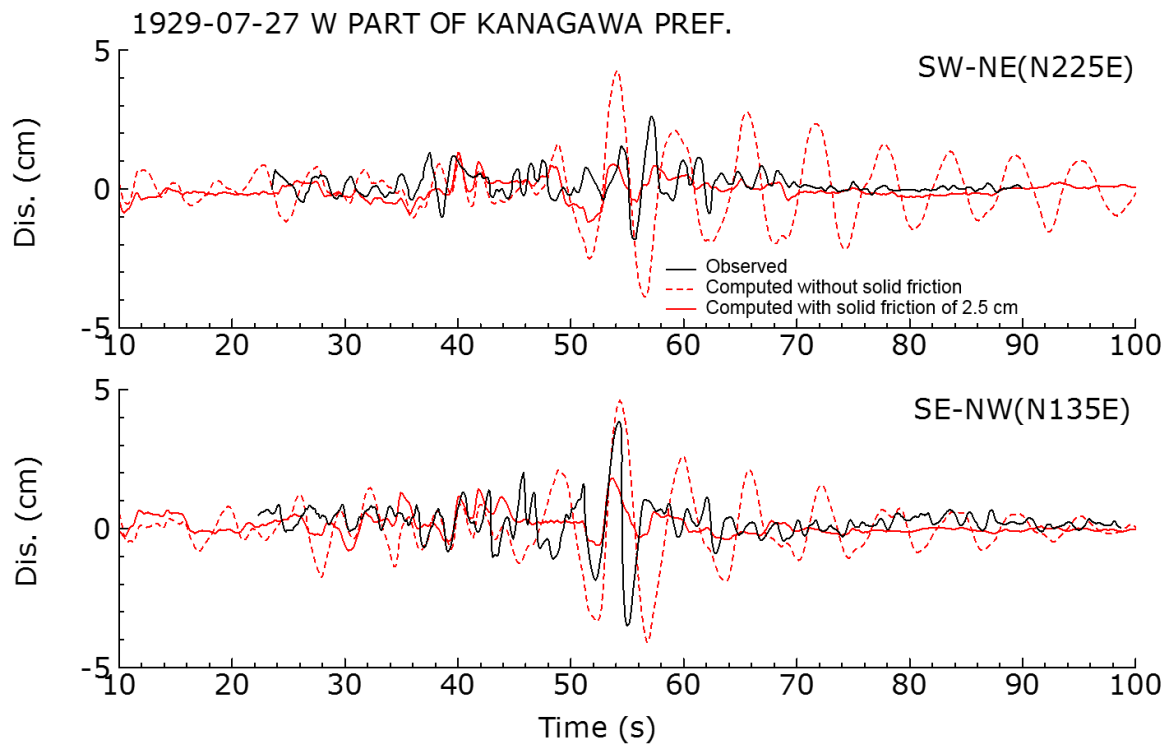


Fig. 4 – Comparison of observed Ewing record with computed one

3. Ewing Seismogram of the Kanto Earthquake

In 1931, Nasu looked for a record of the Kanto earthquake by a request of Prof. Suyehiro, the director of Earthquake Research Institute, who was preparing for his famous lecture on engineering seismology in the U. S. [1,12]. He found a Ewing seismogram of the earthquake at Hongo and traced it by hand on a tracing paper carefully [1]. Figure 5 shows the seismogram of the Kanto earthquake traced by Nasu [16]. Unfortunately the original seismogram is not remain. The traced seismogram consists of four series of the traces which are lines of discontinuity due to scale-out of the indicator of the seismograph, such as A-G series, a-g series, 1-11 series and I-XVII series. Figures 6 show the four series of the traces converted to the X-Y coordinates.

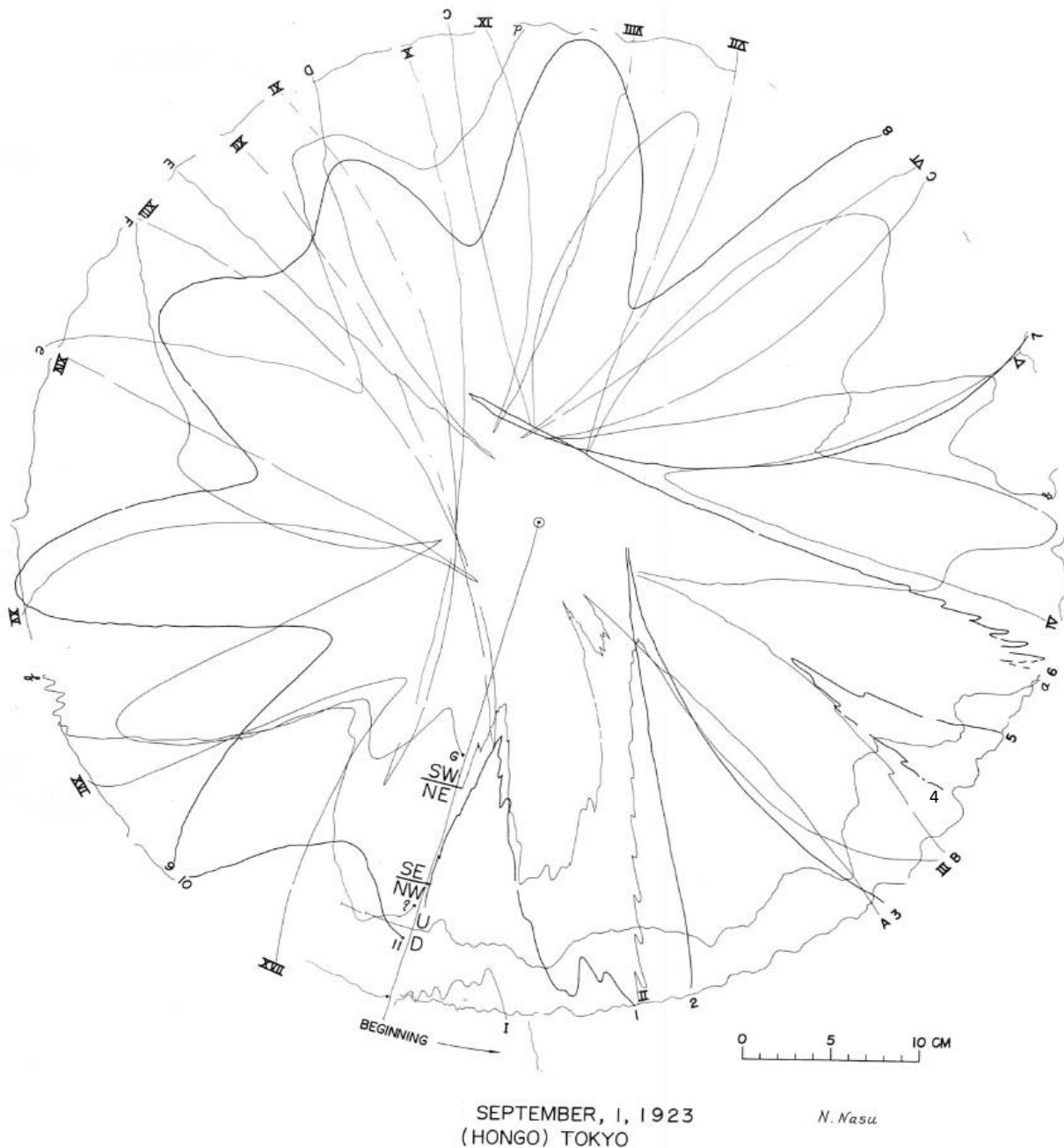
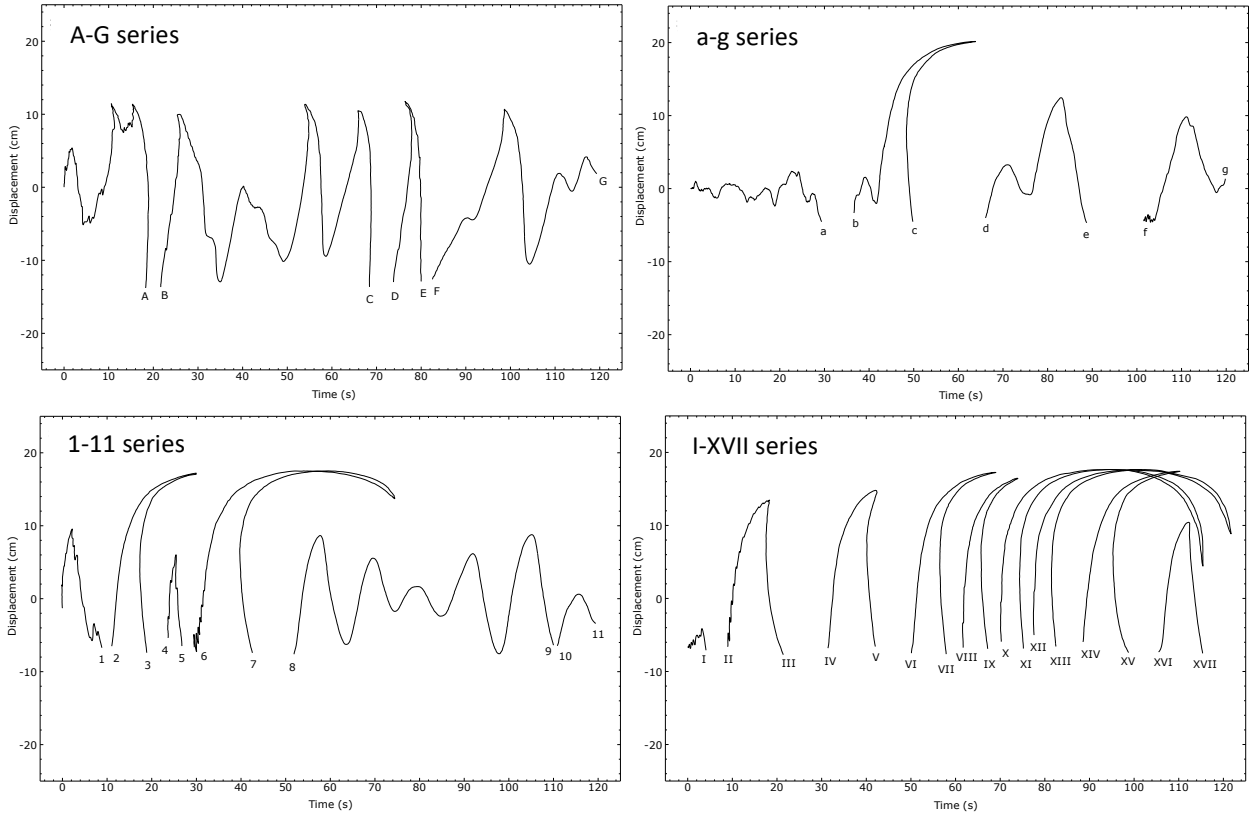
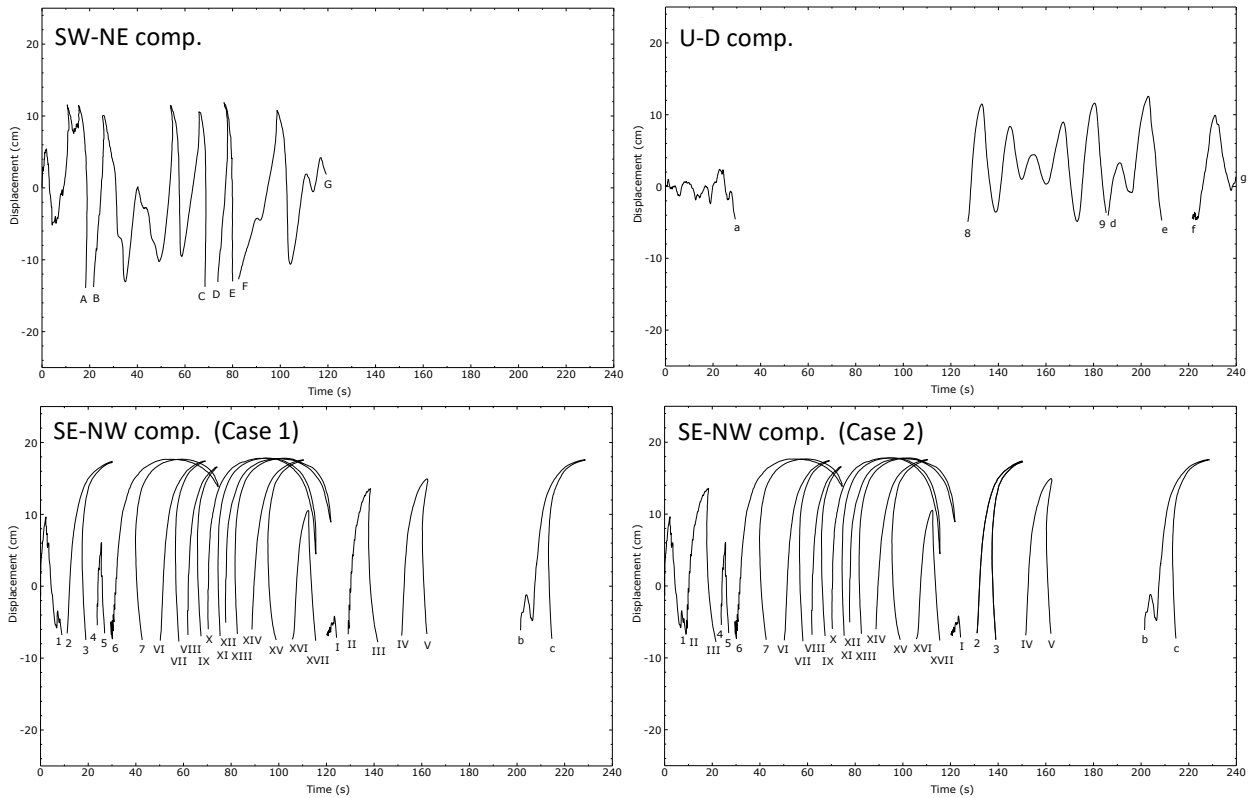


Fig. 5 – The Ewing seismogram of the Kanto earthquake (after Nasu [15])

As has been shown in Fig. 2, the seismograph consists of two horizontal (SW-NE and SE-NW) and one vertical components. The directions of two horizontal pendulums were reverse with respect to the rotation of the recording paper, which makes the direction of the arm length curvatures for two horizontal components reverse. No curvature occurs to the trace for the vertical component. From the curvature, it is considered that the A-G series are for the SW-NE component, the b-c, 1-7 and I-VXII series are for the SE-NW component, and the a and 8-11 series are for the Up-Down component. Since Nasu [4] reported that these traces were registered at the first and second rounds, the b-c, 1-7 and I-VXII series for the NE-SW component are not only for the first 120 sec but also for the next 120 sec.



Figs. 6 - Traces of the Ewing seismogram converted to X-Y coordinates



Figs. 7 – Interpreted traces for three components



Based on the direction of the curvature, these traces can be broken down into those for three components. The interpreted traces for three components are shown in Figs. 7. For the SE-NW component, there are two possibilities as shown by case 1 and case 2. Although there are difficulties in arm length and skew correction of some traces, the arm length and skew correction was tentatively performed. Figure 8 shows the interpreted record after arm length and skew correction. The result is same as that by Nasu and Morioka [5] for the SW-NE component, but is different from that by Nasu et al. [7] for the SE-NW component.

The maximum amplitude of the trace is about 20 cm with period of 13 sec for the SW-NE component and about 40 cm with period of 7 sec for the SE-NW component, however the results are tentative. This suggests that the ground motion of SE-NW component has larger amplitude and shorter period. Since there are the off-scale parts for both components, further investigation such as restoration of the off-scale parts and the instrumental correction should be necessary to discuss the characteristics of the ground motion more precisely.

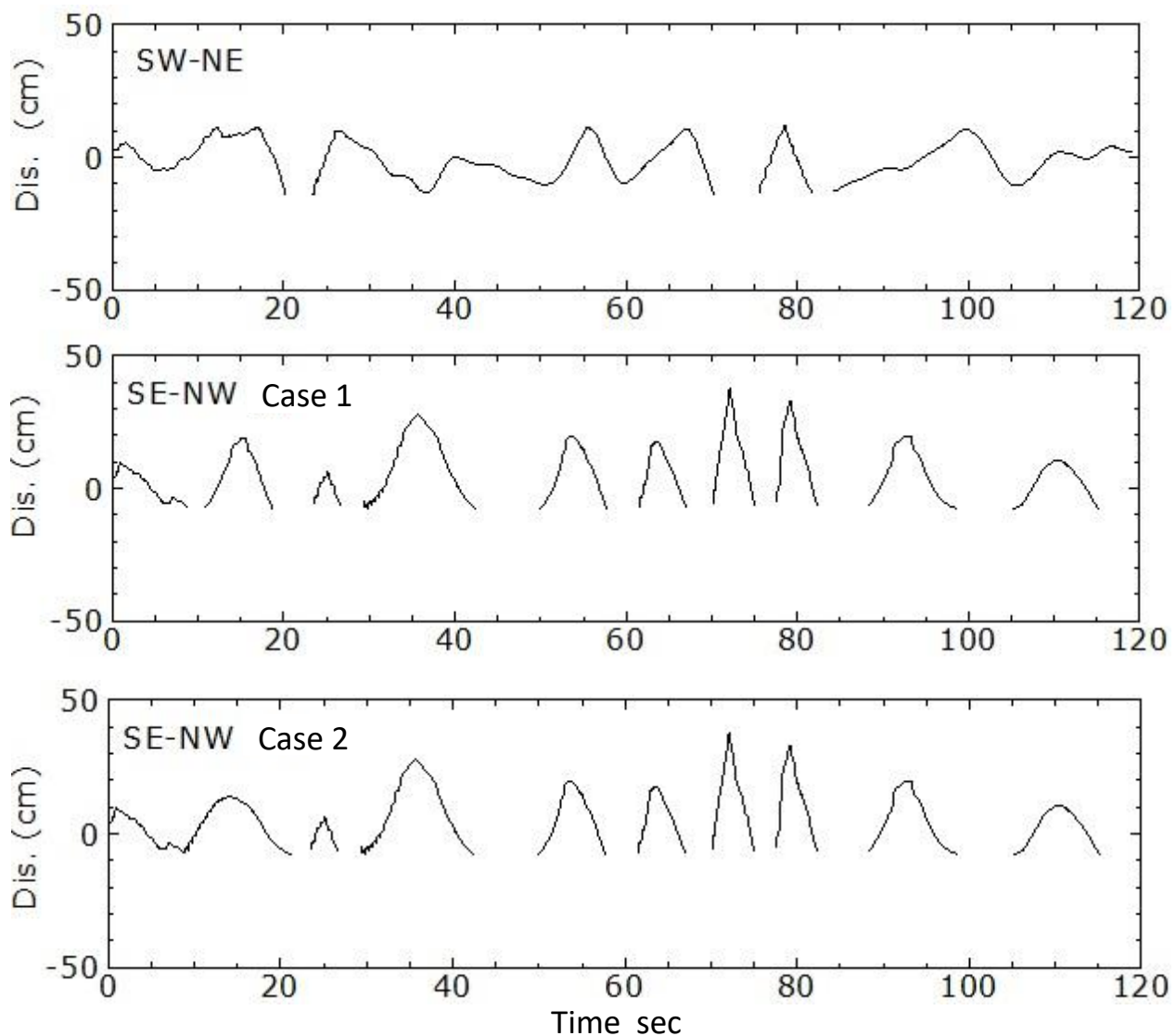


Fig. 8 – Interpreted horizontal record after arm length and skew correction



It has been pointed out that the Ewing seismogram shows significantly different amplitudes and spectra from the Imamura seismogram at the same location [8]. This comparison was made for the restored records. Since there should be many uncertainties in the restoration process of these off-scale or saturated seismograms, the difference may come largely from the restoration process. Figure 9 shows comparison of the raw data of the Ewing and Imamura seismograms. The Ewing data are rotated to the NS and WE components. The natural periods of the Imamura seismograph are about 10 sec for the horizontal component and about 5 sec for the vertical component [13] which are not much different from those of the Ewing seismograph. The Imamura seismogram is saturated by the amplitude of about 3 cm due to collision of the damper plate against the oil tank wall. Considering the saturation of the Imamura seismogram, both seismograms seem to be consistent each other in the beginning part. This may suggest that both seismographs might function properly at least in the beginning part.

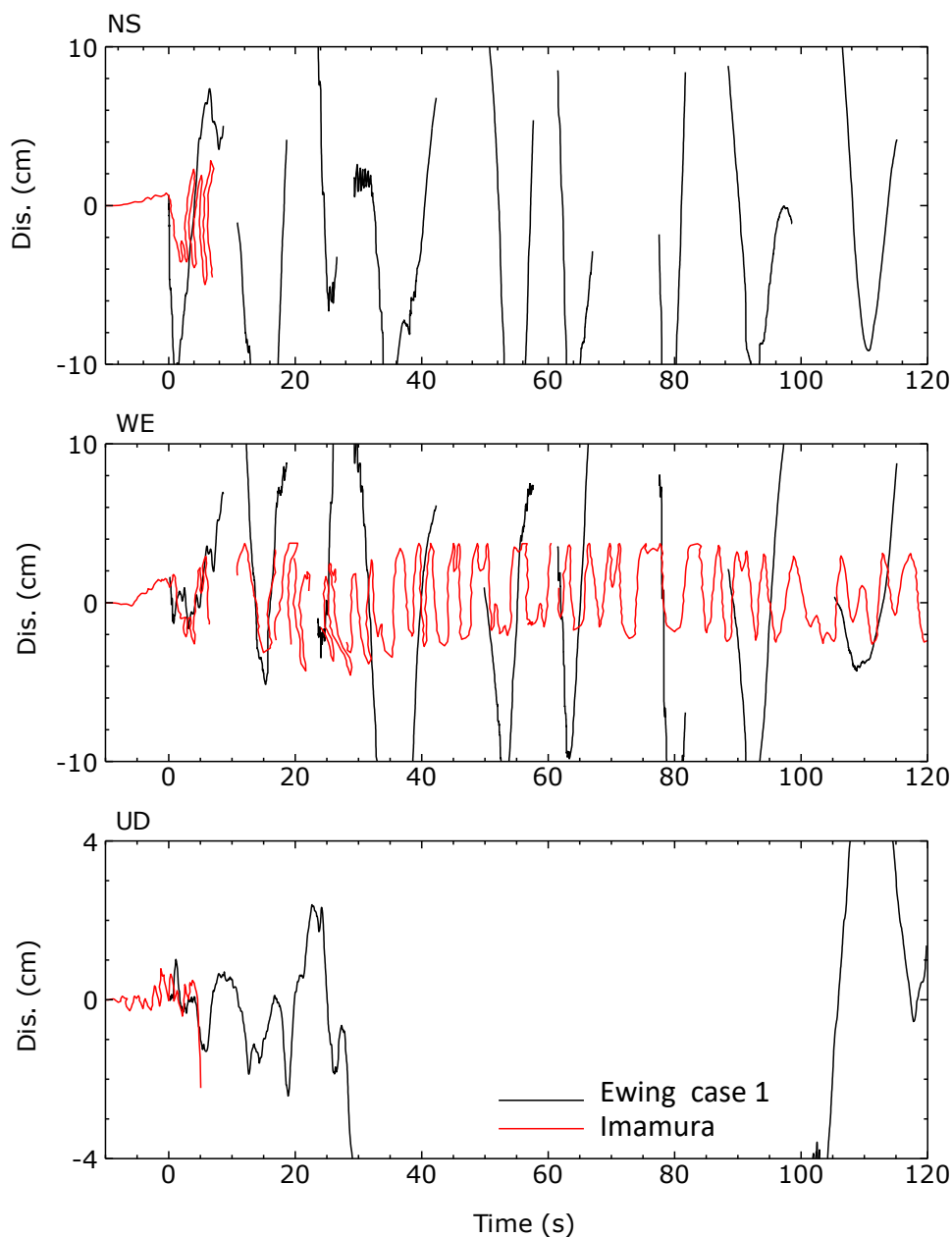


Fig. 9 - Comparison of the raw data of the Ewing and Imamura seismograms



4. Conclusions

The Ewing seismogram of the Kanto earthquake at Tokyo was digitized and interpreted. The tentative results of the interpreted horizontal record show the maximum amplitudes of about 20 cm with period of 13 sec and of about 40 cm with 7 sec for SW-NE and SE-NW components, respectively. The interpreted record of the Ewing seismogram seems to be consistent with the saturated Imamura seismogram at the same location. To reveal the ground motion of the Kanto earthquake at Tokyo more quantitatively, further investigation such as restoration of the off-scale parts and the instrumental correction should be necessary.

Acknowledgements

We thank Dr. Satoko Murotani, National Museum of Nature and Science, for her cooperation in collecting Ewing seismograms and information about the seismographs.

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