Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Characteristics of long-period ground motions in the Tokyo metropolitan area based on seismometer array with broad period band

Kunio Wakamatsu, Arihide Nobata, Osamu Kurimoto & Yuzuru Yasui
Technical Research Institute, Obayashi Corporation, Japan

ABSTRACT: Regional array observation is being conducted to investigate the characteristics of long-period ground motions in the Tokyo Metropolitan Area. Observation records show that some shallow earthquakes which have their hypocenters in the southern part of the Kanto area have two groups of eminently predominant long-period components (seven or eight seconds) appearing in the later phases of seismic motions. Investigation revealed that these waves are Love waves which have different generation mechanisms, and that their vibration characteristics are greatly affected by the radiation characteristics of the hypocenter and the geological environment of the hypocentral region. Finally, ground motions of the Kanto Earthquake of 1923 (M7.9) which occurred in the south Kanto area were estimated.

1 . INTRODUCTION

Mainly with the aim of investigating the behavior of ground in the long-period range during earthquakes in the Tokyo Metropolitan Area, the authors have been conducting a regional array observation using broad band, high-resolution seismometers since 1989. Directing attention to shallow interplate earthquakes that occur in the south Kanto area, this paper demonstratively discusses the predominant long-period wave components, amplitude characteristics and the generation mechanism of these earthquakes, on the basis of observation records. This paper also exemplifies the evaluation of the strength of design input earthquake motions in the long-period range in the Tokyo area.

2 . OBSERVATION POINTS AND THE OUTLINE OF ANALYZED EARTHQUAKES

As shown in Fig. 1, array observation is being conducted at five points: Kawasaki (KWS), Kitasuna (KTS), Funabashi (FNB) and Kiyose (KYS) located on a sedimentary layer in the Kanto Plain, and Usami (USM) located on the bedrock, Seismometers used are servo-type velocity seismometers which have a frequency range of 0.025-70Hz and a measuring range of 0.01-100 kine. In this paper, data obtained from Kawasaki, Kitasuna and Funabashi, which are all located on the shore of Tokyo Bay, is considered. The earthquakes analyzed are the Izuhanto Toho-oki Earthquake (July 9, 1989; M_J=5.5; D=2km) (hereafter referred to as "EQ1") and the Izuoshima Kinkai Earthquake (February 20, 1990; MJ=6.5; D=17km) (hereafter referred to as "EQ2"). Fig. 1 shows the locations of the epicenters of the two earthquakes, along with the observation points. Velocity seismograms for the horizontal components of the two earthquakes in the direction tangential to the epicenter are shown in Fig. 2 (Data for EQ1 at KTS is not available since no seismometer has been installed there.). As seen from Fig. 2, distinctive later phases consisting mainly of long-period components are recognized after principal motions consisting mainly of S waves in records of the two earthquakes. This tendency is particularly pronounced with EQ2.

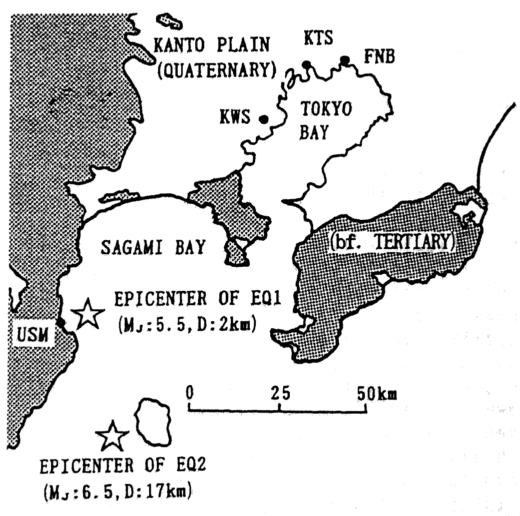

Fig.1 Observation Points and Analyzed Earthquakes

Fig. 3 shows two-dimensional velocity response spectra, at a damping constant of 5%, of EQ1 and EQ2 observed at each point. This figure shows that as far as long-period components of several seconds or more are concerned, both earthquakes have distinctive peaks at periods of seven or eight seconds. It is noteworthy that the amplitudes are hardly reduced despite the increases of the epicentral distance.

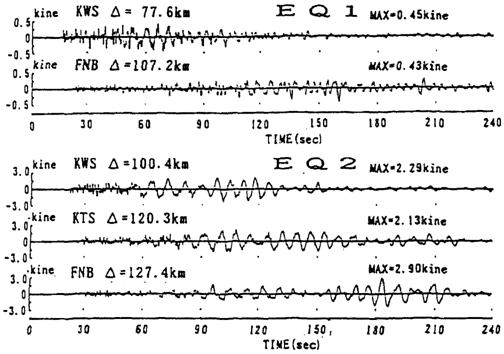

Fig.2 Seismograms of EQ1 and EQ2 (Transverse Component)

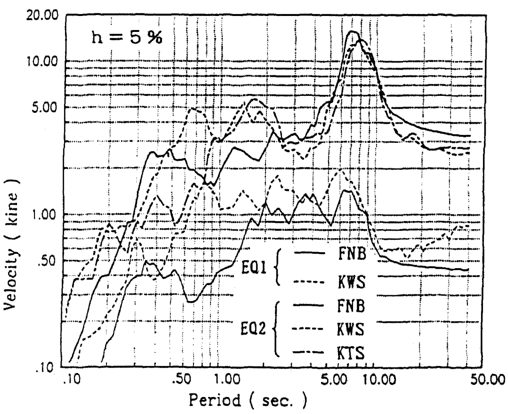

Fig.3 Velocity Response Spectra (2-D)

3. WAVE COMPONENTS IN LATER PHASES AND PLACES OF THEIR GENERATION

Wave forms have been passed through a band-pass filter with a period of about seven seconds, where the response spectrum shows a peak. Fig. 4 show these wave forms in proportion to the epicentral distance from each observation point. Similarity between the group velocities of the two wave forms shown in these figures indicate that the two waves have similar properties. Notice that both wave forms clearly show a first wave group followed by a second wave group after an interval of about 40 seconds. However, the amplitude characteristics of these wave forms have marked differences: EQ1 has greater amplitudes in the first wave group, while EQ2 has greater amplitudes in the second wave group.

Fig. 5 compares the group velocity of EQ2 between KWS and KTS for other period components with the group velocity of Love waves determined from the deep ground structure of the Tokyo area (Shima et al. 1976). As shown, the results of observation agree well with the results ofcalculation. It can be considered, therefore, that the principal wave components in this period range are Love waves.

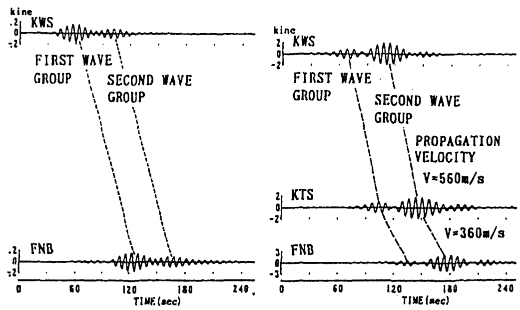

Fig.4 Band-Pass Filtered (T=7.0sec) Seismograms at each Observation Points

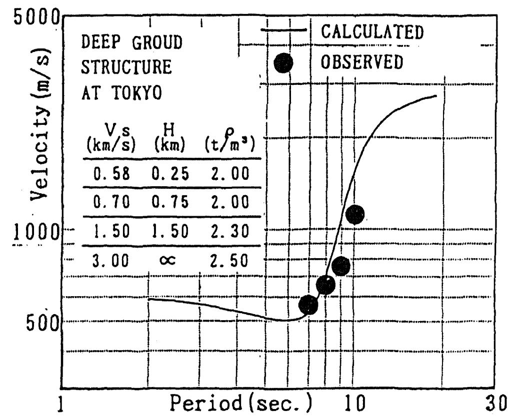

Fig.5 Comparison of Group Velocities due to Love-wave between observed values and Theoretical Results obtained from deep Ground Structure in Tokyo

As a next step, the places of generation of these Love waves were considered. From the group velocity of Love wave in the Kanto Plain abovementioned and it of the Sagami Bay area (Yamanaka et al. 1990), the crustal structure of the Kanto area and absolute times indicated by observation records, the places of generation of the first and second wave groups were determined by establishing consistency in time records. The places of generation thus obtained are shown in Fig. 6. It can be concluded, therefore, that the waves in the first group are Love waves

transformed from body waves near the boundaries of the Quaternary deposits and the Tertiary or older layers in the Kanto Plain, as pointed out by Yokota et al. (1986).
It can also be concluded that as pointed out by Yamanaka et al. (1990), the waves in the second group are Love waves which were generated by a thick sedimentary layer in the Sagami Bay area and have come into the Kanto Plain.

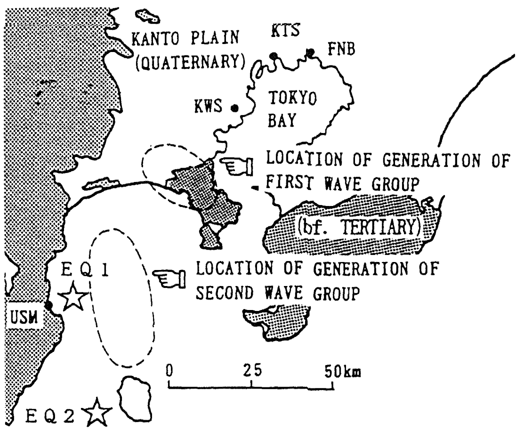

Fig.6 Locations of Generation of Love Wave

4. AMPLITUDE CHARACTERISTICS AND GENERATION OF LOVE WAVES

The amplitude characteristics of the waves in the first and second groups were investigated using the wave forms observed at FNB. The first and second wave groups were identified on the basis of the wave forms in the direction of the major axis of the plane orbit, and a Fourier spectrum for each group was obtained. The ratio of the Fourier spectrum for each of the two earthquakes to that for the principal motions (S waves) was calculated. The ratios thus obtained are shown in Fig. 7. The S wave portions in the observation records were obtained as the root mean square of two horizontal components.
As shown, with regard to the first wave groups, the predominant periods of the two earthquakes are somewhat different, but in both cases the magnification is about 30-40, and hence the difference between the two earthquakes is not significant. Therefore, a generation mechanism in which inputs and outputs are linearly related to some extent can be assumed. Concerning the second wave groups, both EQ1 and EQ2 have a relatively narrow, pointed peak observed at a period of around seven seconds. The peak value of EQ2 is as high as 80 or so. The peak value of EQ1, by contrast, is about 30, which is lower than the peak values of the first wave group, showing a considerable difference between the two earthquakes.
Fig. 8 shows the Fourier spectrum for the above-mentioned S wave portion in the form of displacement spectrum. The figure also shows a displacement spectrum by Savage (1972) where the radiation factor at a distant point is set at 1. Both earthquakes show a substantial agreement with the theoretical spectrum, and neither of the analyzed earthquakes shows deviating periodicity or radiation characteristics. Probably, this is partly because radiation characteristics are smoothed under the influence of the heterogeneity of ground acting as a medium of propagation from the hypocenter. In defining the theoretical spectrum, an internal damping of Q=500 was assumed, and that was doubled throughout the period range to reflect the amplifying effect of the unconfined ground surface. The amplifying effect of subsurface deposits was not removed from the observation records.

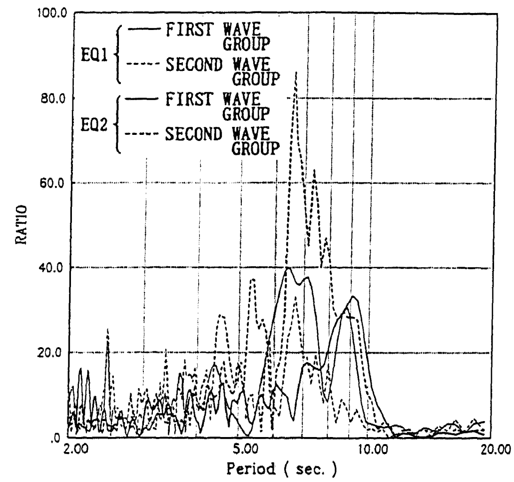

Fig.7 Amplitude Spectral Ratio of First and Second Wave Group (Love-Wave) to Principal Motions (S-Wave)

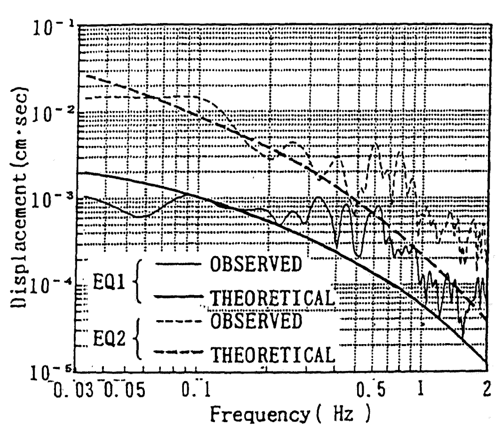

Fig.8 Comparison of Fourier Amplitude Spectra due to S-Wave between observed values and Theoretical Results

Fig. 9 shows the earthquake mechanisms (J. M.A.1990a,1990b) of the two earthquakes, along with their epicenters. This figure is aimed at helping to understand the differences in the amplitude characteristics of the second wave groups. As shown, the nodal surface of P waves in EQ2 is roughly directed toward the observation points in the Metropolitan Area. This direction is close to the direction of the maximum radiation of S waves, indicating the possibility of Love waves, being generated in the Sagami Bay area. While, in EQ1, the principal axis of P waves is roughly directed toward the observation points, indicating that Love waves are not likely to be generated in the Sagami Bay area which is near the hypocenter. Such orientation of the earthquake mechanism and amplification characteristics due to the geological structure around the hypocenter which will be shown in the next chapter are considered to greatly affect the amplitude characteristics of the second wave group.

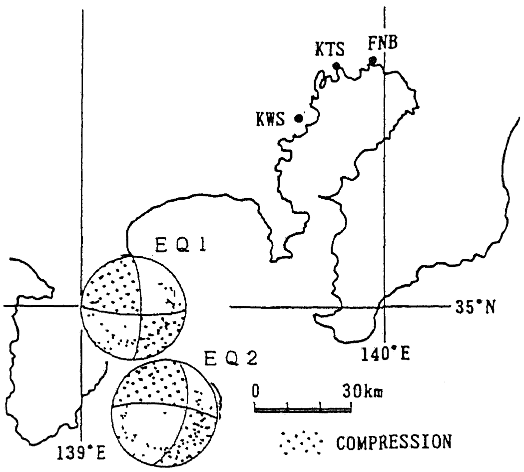

Fig.9 Mechanism solutions of EQ1 and EQ2

5 .THREE-DIMENSIONAL FEM ANALYSIS OF THE AMPLITUDE CHARACTERISTICS OF SECOND WAVE GROUP

A three-dimensional FEM analysis was performed to investigate the amplitude characteristics of the second wave group macroscopically. The ground structure of the Sagami Bay and adjacent areas was estimated on the basis of past studies(Yamanaka et al.1990), (Honza 1984), (Kasahara 1984). Simplified analytic models of the two earthquakes including their hypocenters, as shown in Fig. 10, were developed. As shown, there is a thick sedimentary layer to the southeast of the Sagami Bay area, and there is a fault to its east. Thus, the area is surrounded, except in the southeast direction, by relatively hard layers. Also shown in the figure are the directions of the epicenters of the two earthquakes and the observation point KWS. External force at the hypocenter was assumed to be horizontal double-couple force. The depth of this force was set at 2km for EQ1 and 5km for EQ2, on the basis of aftershock distribution and other observation data(N.R.I.E.S.D. P.1990).

	S-WAVE VELOCITY (km/s)	P-WAVE VELOCITY (km/s)	DENSITY (g/cm^3)	DAMPING FACTOR
①	1.5	2.6	2.0	0.01
②	2.5	4.6	2.2	0.01
③	3.0	5.5	2.4	0.01

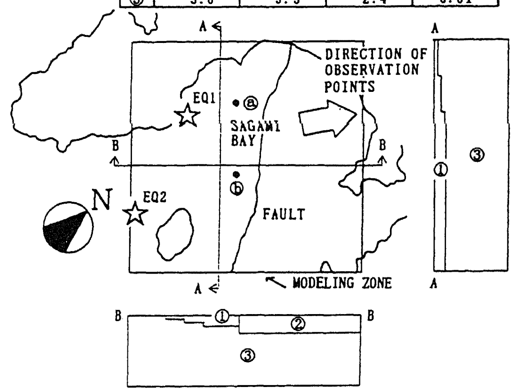

Fig.10 3-Dimensional Analitical Model in and around Sagami Bay

Fig. 11 shows the vibration modes in the vertical direction at a period of eight seconds at points ⓐ and ⓑ in the direction of the observation points. Fig. 12 shows the ratio of the average amplitudes at the adjacent nodal points of point ⓑ for EQ2 at the ground surface to the average amplitudes at the adjacent nodal points of point ⓐ for EQ1 (the ratio between the transfer functions) in a direction tangential to the hypocenter. Fig.11 shows that the vibration modes resemble the forms of Love waves.

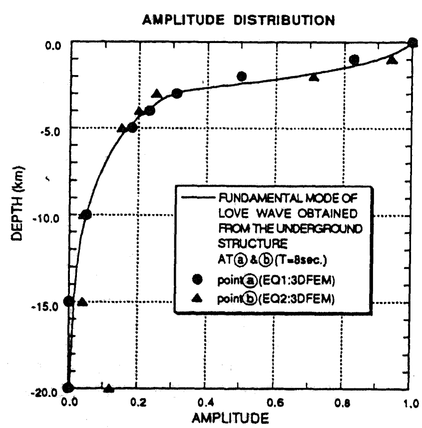

Fig.11 Comparison of Vibration Mode at T=8sec between 3-Dimensional Analitical results and Fundamental Mode of Love-Wave

Fig. 12 shows that on the whole EQ2 has greater amplitudes in the long-period range. At periods of about eight seconds, in particular, EQ2 has amplitudes about two times greater than those of EQ1. As abovementions, the underground structure of Sagami Bay is not clear , so a detailed comparison of the predominant period between the observed and analytical results is not so significant. However, this tendency is consistent with the observation records, indicating that the orientation of the earthquake mechanism and the geological environment of the hypocenter greatly affect the long-period components in the later phases of seismic motions.

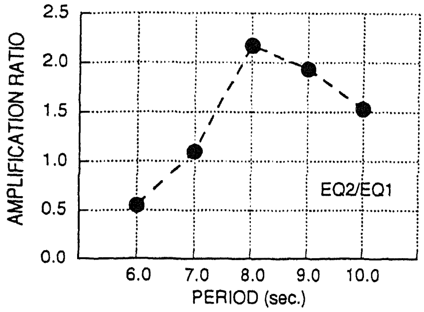

Fig.12 Ratio of Average Amplitude near Points ⓑ of EQ2 to Average Amplitude near Points ⓐ of EQ1

6. ESTIMATION OF GROUND MOTION IN TOKYO OF THE KANTO EARTHQUAKE OF 1923

The ground motion of the Kanto Earthquake of 1923 (September 1, 1923; MJ=7.9) is one of the widely used designinput ground motions for the Tokyo Metropolitan Area. In this study, ground motion at KTS was estimated using the fault parameters for the Kanto Earthquake shown in Fig. 13. (Matu'ura 1980). The wave form synthesis method of Irikura (1981) was adopted as an estimation method, and EQ2 was used as an elementary earthquake. The numberof fault segments (n) was set at n=5 according to the relation between magnitude and seismic moment (Sato 1979), and destruction was assumed to propagate radially from the starting point. In connection with the correction of distances, space damping was used as the -0.5th and -1.0st power of the distance (X), considering surface and body waves. Judging from the results of the array observation, deep earthquakes hardly have longperiod components. Hence, calculation was performed for two cases in which the elementary earthquake was applied only to three-fifths or two-fifths of a relatively shallow area in the southern part of the fault plane. Fig.14 shows the results of calculation in the form of the velocity response spectrum at a damping constant of 5%. These spectra mean the average of 10 spectra which have some variations in the rupture velocity and rise time respectively. As shown, the velocity response spectrum in the Tokyo area at long periods of seven or eight seconds could take the values of 150-300 kine.

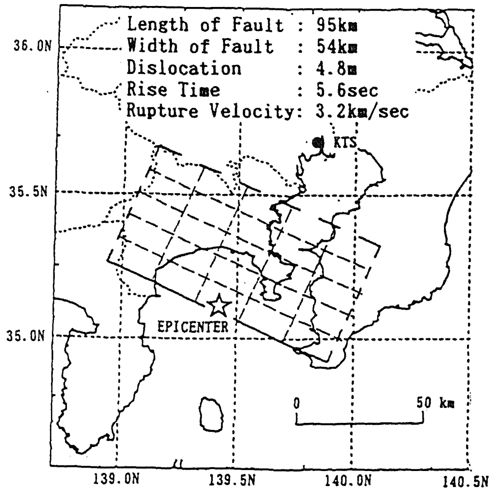

Fig.13 Fault Parameters of Great Kanto Earthquake

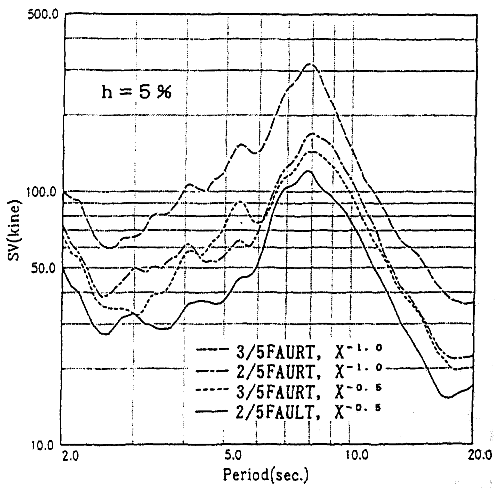

Fig.14 Predicted Velocity Response Spectrum of Great Kanto Earthquake at KTS

7. CONCLUSION

Two types of Love waves caused by shallow earthquakes having their hypocenters in the south Kanto area, which are observed in the Tokyo Metropolitan Area, have been analyzed. Waves in the first group are considered to be Love waves transformed from body waves into surface waves near the perimeter of the Kanto Plain, and ones in the second group are considered to be Love waves generated in the Sagami Bay area under the influence of the radiation characteristics of the hypocenter. It is thought that the former are hardly affected by the radiation characteristics of the hypocenter because of the heterogeneity of ground between the hypocenter and the boundary of the sedimentary layer acting as a medium of propagation. By contrast, the latter are considered to be affected greatly by radiation characteristics and the geological environment of the hypocenter. It has been confirmed that the latter could have far greater amplitudes.

One of the types of damage-causing earthquakes in the Metropolitan Area is a group of large-scale earthquakes, including the Kanto Earthquake of 1923, which have their hypocenters in the south Kanto area. It is to be fully noted that earthquakes that have their hypocenters in this area have the potential to generate Love waves having extremely great amplitudes, such as those of the second wavegroup of EQ2. This implies a need to chose seismic waves very carefully in estimating ground motions by the wave form synthesis method or other statistical analysis methods.

Finally, the ground motions of the Kanto Earthquake in the Tokyo Metropolitan Area were estimated. As a result, it was confirmed that at relatively long periods of seven or eight seconds, the velocity response spectrum at a damping constant of 5% could take the values of 150-300 kine.

ACKNOWLEDGEMENT

The authors wish to express their thanks to Mr.Fujimori, researcher at the Technical Research Institute, Obayashi Corporation, who allowed the authors the use of his computer program for wave form synthesis calculation.

REFERENCES

Shima, E., M. Yanagisawa, K. Kudo, K. Seo and K. Yamazaki:On the Base Rock of Tokyo. II.Observations of Seismic Waves Generated from the 3rd Yumenoshima and Yoshikawa Explosions.;Bull.Earthq.Res.Inst. Vol.51 (1976), pp.45-61

HONZA E.:Subduction along the Sagami and Suruga troughs, central Japan., The Quaternaly Research ,vol.23, No.2, 1984 (in Japanese)

Yokota, H., S. Kataoka and T. Tanaka:Characteristics of Earthquake Ground Motions in Period of 1 to 15 Seconds Observed in Tokyo; Proceedings of 7th JEES, 1986

Yamanaka, H., K. Seo and T. Samano:Characteristics of Long-period Ground Motions Observed on the Southwestern Kanto Plain, Japan: Proceedings of 8th JEES, 1990

Savage, J. C.:Relation Corner Frequency to Fault Dimensions;Jour. Geophys. Res., 77, 3788 (1972)

J.M.A. 1990a:Seismic Activity in and around the Izu Peninsula(May-October, 1989);Rep. Coord. Comm. Earthq. Pred. Vol 43, pp.140-156

J.M.A. 1990b:On the Earthquake(M6.5) near the Izu-Oshima Island, February 20, 1990; Rep. Coord. Comm. Earthq. Pred. Vol 44, pp.147-152

KASAHARA, et al.:MULTI-CHANNEL HANSHA-HO ZISINTANSA NI YORU IZU-TOHO-OKI HIKA-KOZO , Program and Abstracts No.2, The Seismological Society of JAPAN, 1989 (in Japanese)

National Research Institute for Earth Science and Disaster Prevention:Earthquake of near Izu-Oshima(M6.5) on February 20, 1990; Rep. Coord. Comm. Earthq. Pred. Vol 44, pp.153-158

Matsu'ura, M., T. Iwasaki, Y. Suzuki and R. Sato: Statical and dynamical study on faulting mechanism of the 1923 Kanto earthquake: J. Phys. Earth, 1980, 28, pp.119-143

Irikura, K. and I. Muramatsu:YOSHIN YA ZENSHIN NO SHINDOUKIROKU KARA HONSHIN NO SHINDOU KIROKU WO GOUSEI SURU HOUHOU, Program and Abstracts No.2, The Seismological Society of JAPAN, 1989 (in Japanese)

Sato, R.:Theoretical basis on relationships between focal parameters and earthquake magnitude;J. Phys. Earth, 1979, 27, pp.353-372