13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 436

THE DURATION AND AMPLITUDE CHARACTERISTICS OF EARTHQUAKE GROUND MOTIONS WITH EMPHASIS ON LOCAL SITE EFFECTS

Y. Shoji[1], K. Tanii[2] and M. Kamiyama[3]

SUMMARY

Among various indices of earthquake ground motions, the maximum amplitude value and frequency content have been regarded as the most important indices for earthquake engineering. These indices are strongly affected by local site conditions. Also the fact that the duration of earthquake ground motion differs from site to site even during the same earthquake has been noticed by many researchers.

This paper dealt with the duration and its related parameters were adopted as representative parameter of the duration characteristics of earthquake ground motions. We investigated how they are influenced by the earthquake magnitude, hypocentral distance and the focal depth. The average and overall trends of the duration and its related parameters were presented. Also the correlation of the duration and its related parameters with the Japan Meteorological Agency (JMA) instrumental seismic intensity was shown.

A simple statistical technique was performed by using the earthquake ground motion records obtained in the Sendai region, Japan. This paper discusses the variability for the duration and its related parameters with emphasis on the site-dependency and the event-dependency to reveal the duration and amplitude characteristics of earthquake ground motions. The difference of these ground motion parameters is not only site-dependent but also event-dependent. For the total power and rms amplitude, the difference at each site exceeds the variability at each event, and strong site-dependency was found. The variability for the total power, rms amplitude and peak ground acceleration (PGA) indicated essentially the same trends.

On the other hand, it is quantitatively revealed that the event-dependency for the duration is greater than the site-dependency. Among various ground motion parameters, these parameters would be divided into two groups regarding the site-dependency and the event-dependency. One is the ground motion parameter based on "amplitude", and the other based on "duration". In addition, this paper suggested that the duration and amplitude characteristics of earthquake ground motions suffer a reciprocal effect due to the earthquake magnitude, hypocentral distance, the focal depth and the local site conditions.

In view of the results, the duration is not less important than the maximum amplitude and frequency content in earthquake engineering. Furthermore, this paper provided meaningful information of input motion available to earthquake-resistant design.

[1] Department of Engineering, DPS Bridge Works Co., ltd, JAPAN
[2] Department of Environmental Information Engineering, Tohoku Institute of Technology, JAPAN
[3] Department of Environmental Information Engineering, Tohoku Institute of Technology, JAPAN

INTRODUCTION

It has been well known that earthquake ground motions result primarily from the three factors, namely, source characteristics, propagation path of waves, and local site conditions. The third of the three factors is seen as the most effective factor contributing to engineering problem. The importance of the maximum amplitude and frequency content has been recognized. Various indices, for example, peak ground acceleration, peak ground velocity are strongly influenced by local site conditions, such as complex surface geology and irregular topography.

On the other hand, many researchers suggested that the duration of earthquake ground motions differs from site to site even during the same earthquake and the duration plays an important role of engineering problem. The practical importance of understanding the duration characteristics of earthquake ground motions has fueled a great deal of research. Nevertheless, most of the past studies on the duration investigated how the duration is influenced by earthquake magnitude, epicentral distance. It was indicated that the duration, as well as the maximum amplitude and frequency content, are strongly affected by local site conditions. Unfortunately, that these studies dealt with local site conditions qualitatively (*e. g.*, Trifunac and Brady [1]).

There are a few studies the duration is quantitatively associated with not only the earthquake magnitude and epicentral distance but also the local site conditions. Kamiyama [2] conducted a new multiple regression analysis which includes not only the earthquake factors but also the local site conditions as independent variables and applied to the duration and its related parameters.

In this context, therefore, an accurate, quantitative prediction of earthquake ground motions cannot be achieved without understanding the duration characteristics due to the local site conditions. This paper deals with the duration and its related parameters were adopted as representative parameter of the duration characteristics of earthquake ground motions. In order to present the average and overall trends of the duration and its related parameters, we investigate how they are influenced by the earthquake magnitude, hypocentral distance and the focal depth. We also conduct the correlation of the duration and its related parameters with JMA instrumental seismic intensity. Moreover, this paper discusses the variability for the duration and its related parameters with emphasis on the site-dependency and the event-dependency to reveal the duration characteristics of earthquake ground motions.

On the other hand, Shoji *et al.* [3] discussed the variability of ground motion parameter, such as JMA instrumental seismic intensity, peak ground acceleration, peak ground velocity and the product of the peak acceleration and the peak velocity, with the aid of a simple statistical technique. It was quantitatively revealed that the difference at each site exceeds the variability at each event.

In this study, for the same station array and the same data, the same statistical technique applied to the duration and its related parameters to detect the site-dependency and event-dependency for these parameters. By comparing the site-dependency and event-dependency for the duration and its related parameters, we discuss the duration and amplitude characteristics with emphasis on the local site effects.

The objective of this paper is to reveal the duration and amplitude characteristics of earthquake ground motions and to obtain meaningful information of input motions available to earthquake-resistant design, based on observed records of Small-Titan (Shoji and Kamiyama [4]).

ARRAY OBSERVATION SYSTEM USED IN THIS STUDY

The earthquake records used in this study were obtained by an array observation system with high-density. The system, named Small-Titan (Strong Motion Array of Local Lots by the Tohoku Institute of Technology Area Network), was installed in Sendai City, Japan in 1997. This array system consists of 20 observation sites, which have an average of about 4-km for the station-to-station distance. Each observation station was located at various kinds of soils to effectively obtain local site effects.

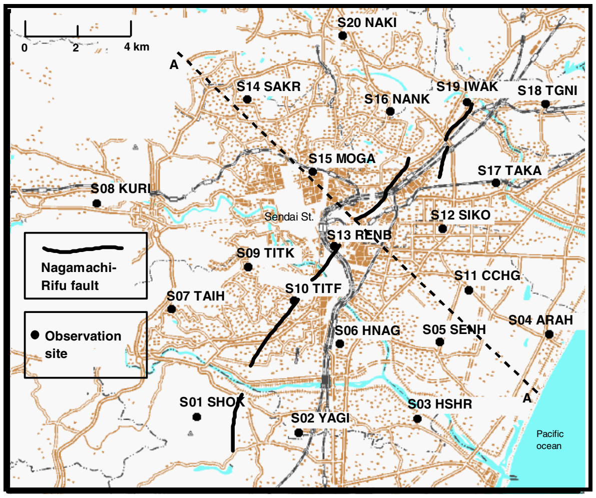

Figure 1: Map of the 20 stations

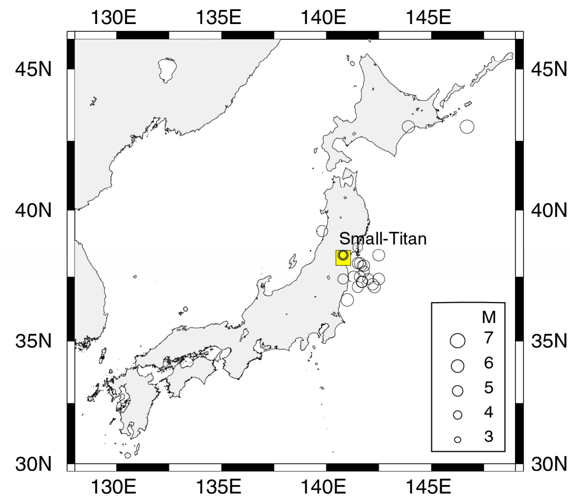

Figure 2: Epicenters of earthquakes used in this study

Table 1: List of events used in this study

	Date (yr/mo/da)	Origin time	Latitude	Longitude	Focal depth (km)	MJ
Earthq_19981124044817	1998/11/24	04:48:17	38.0	141.6	80	5.4
Earthq_19990201015215	1999/02/01	01:52:15	37.1	141.5	50	5.4
Earthq_19990612074350	1999/06/12	07:43:50	37.4	142.0	70	5.2
Earthq_19991005093853	1999/10/05	09:38:53	37.4	142.5	50	5.5
Earthq_19991107215341	1999/11/07	21:53:41	37.4	140.8	80	5.0
Earthq_19991115103443	1999/11/15	10:34:43	38.3	142.5	40	5.7
Earthq_20000109130223	2000/01/09	13:02:23	37.3	141.7	50	5.5
Earthq_20000128232328	2000/01/28	23:23:28	43.0	146.7	60	6.8
Earthq_20000320062558	2000/03/20	06:25:58	38.0	141.5	80	5.4
Earthq_20000603133810	2000/06/03	13:38:10	38.6	141.5	110	4.7
Earthq_20000604203956	2000/06/04	20:39:56	37.9	141.8	60	5.2
Earthq_20000721033929	2000/07/21	03:39:29	36.6	141.0	50	6.1
Earthq_20001116183140	2000/11/16	18:31:40	37.5	141.6	60	5.3
Earthq_20010225065401	2001/02/25	06:54:01	37.2	142.2	10	5.8
Earthq_20010226150841	2001/02/26	15:08:41	37.1	142.3	10	5.6
Earthq_20010412160151	2001/04/12	16:01:51	37.3	141.7	40	5.3

Figure 1 shows a map of the 20 stations. In Figure 1, the Nagamachi-Rifu Fault, an active fault with an activity degree of 1, runs across the center of Sendai City from the southwest to the northeast. Hundreds of earthquakes were recorded by this array. In order to remove the source and path effects, we have chosen the total 16 observed records relatively long source to station distance (over about 100 km), all the data were recorded at all 20 stations. They were composed of all three components. Table 1 gives the source locations, focal depth, the Japan Meteorological Agency magnitude (M_J). Figure 2 shows epicenters of earthquakes used in this study.

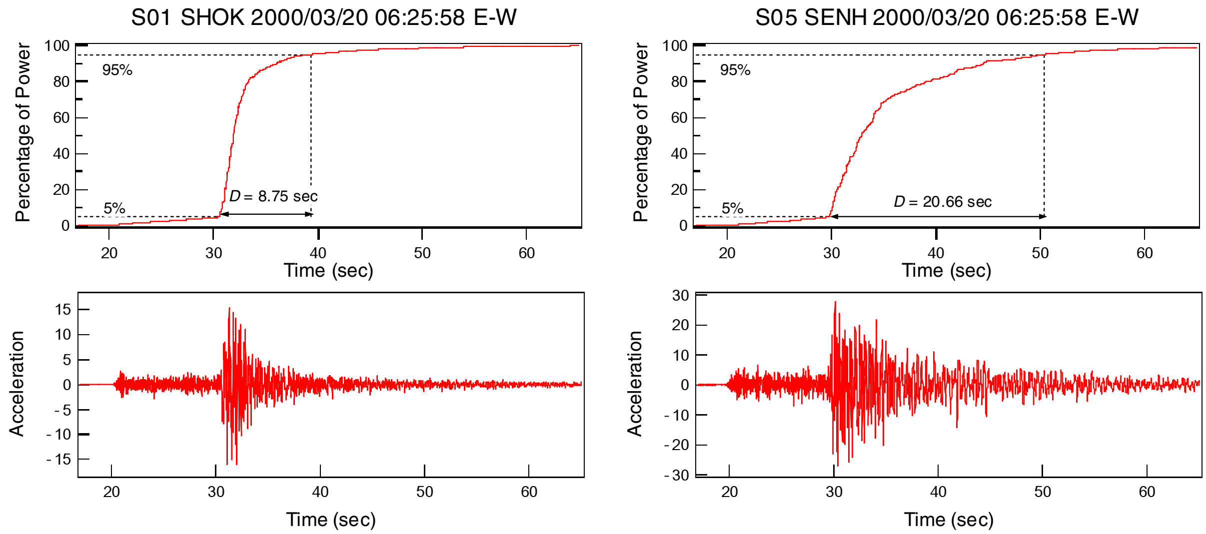

Figure 3: The duration and Husid plots for typical earthquake ground motions

DEFINITION OF THE DURATION AND ITS RELATED PARAMETERS

The major difficulty in studying the duration characteristics is how to define the duration earthquake ground motions. There have been several proposals for defining the duration earthquake ground motions. However, the purpose of this paper is not review the superiority of each definition but to examine the characteristics of the duration influenced by various factors.

For this study, the definition of the duration proposed by Trifunac and Brady [1] was used to examine the characteristics of the duration affected by various factors. The duration due to the power, is determined as difference between the maximum and minimum of t which satisfy the expression

$$0.05 \le \int_0^t a^2(t)dt \Big/ \int_0^T a^2(t)\,dt \le 0.95, \qquad (1)$$

where $a(t)$ is an earthquake record and T is its time length. As shown in equation (1), this definition means the time interval in which 90 percent of the total power $a(t)$ is involved. This duration is D, "total power" P_r, and "root mean square amplitude" V_{rms} were also defined by

$$P_r = \int_0^T a^2(t)dt\,, \qquad (2)$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T a^2(t)dt}\,. \qquad (3)$$

Figure 3 shows the example of D, the process to accumulate the power, which was called the "Husid plot" by Dobry *et al.* [5], is illustrated. We can see in Figure 3, the amplitude and the duration vary significantly reflecting the local site conditions.

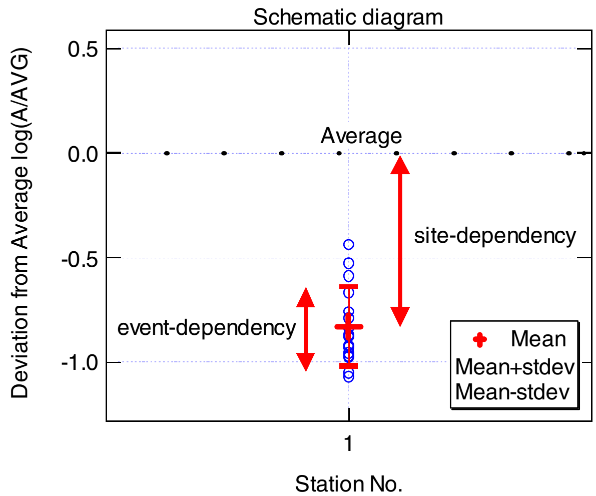

Figure 4: Schematic diagram of the site-dependency and event-dependency for ground motion parameters

DEFINITION OF LOCAL SITE EFFECTS

Many studies divide the factors influencing earthquake ground motions into source, path, and site effects, a distinction that has proven to be useful for understanding and predicting seismic motions (Aki [6]). The study of local site effect on strong ground motions is one of the most important goals in earthquake engineering. An accurate, quantitative prediction of earthquake strong motions cannot be achieved without understanding the local site effect.

On the contrary, the ambiguous meaning of site response and the lack of a clear definition of local site effects were indicated (Field [7]). Furthermore, Field [7] indicated that the local site effect inevitably involves an intrinsic variability due to different incidence angles, azimuths, and wave types. In spite of these indications, to warrant usefulness of the local site effect for understanding and predicting seismic motions, the difference between sites must exceed the intrinsic variability at each site (Aki [6]).

In this context, therefore, we adopt a simple statistical technique, described below, to estimate the site-dependency and event-dependency. This approach in estimating the site-dependency of ground motion parameter from earthquake data is removing the source and path effects. As described below, assuming that all 20 stations have similar source and path effects, the resulting ratio constitutes an estimate of the site-dependency. The site-dependent term SDT is defined as

$$SDT = \log(\frac{A}{AVG}), \qquad (4)$$

where A is ground motion parameter; AVG is averaged over A from all stations. The site-dependency and event-dependency were obtained by averaging SDT from all the events used in this study. Figure 5 shows schematic diagram for the variability of ground motion parameter. In Figure 4, the site-dependency was defined as the deviation from the average. Also the event-dependency was defined as a deviation band, given by the average plus and minus standard deviation, is shown in Figure 4.

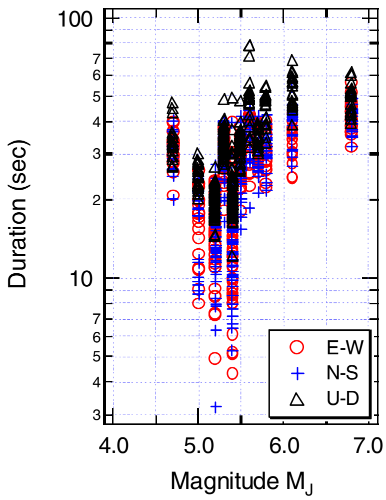

Figure 5: Correlation between the duration and earthquake magnitude M_J

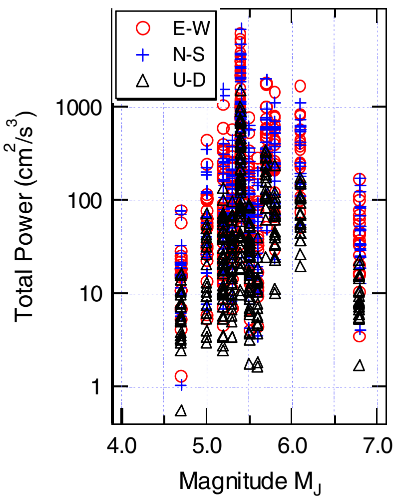

Figure 6: Correlation between the total power and earthquake magnitude M_J

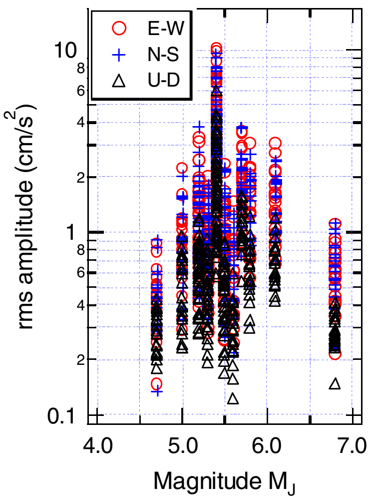

Figure 7: Correlation between rms amplitude and earthquake magnitude M_J

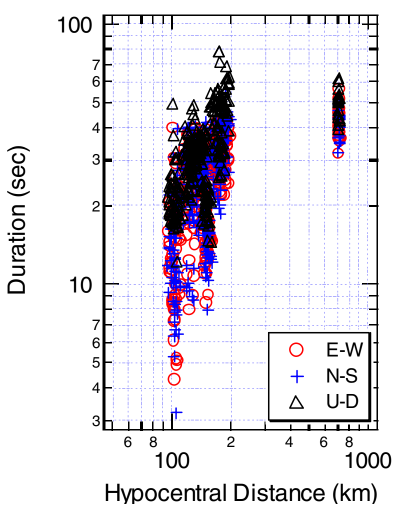

Figure 8: Correlation of the duration with hypocentral distance

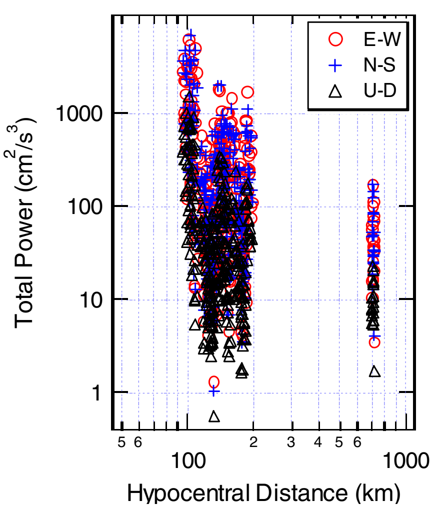

Figure 9: Correlation of the total power with hypocentral distance

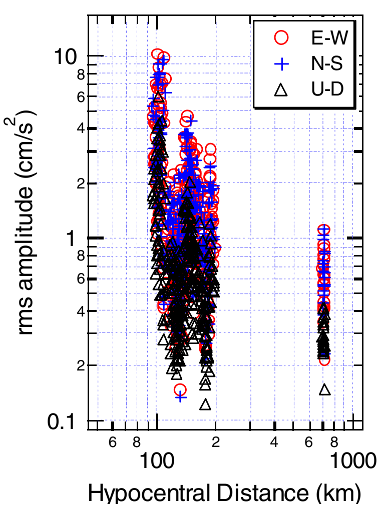

Figure 10: Correlation of rms amplitude with hypocentral distance

RESULT

Average and overall trend for the duration and its related parameters

In order to present the average and overall trends of the duration and its related parameters, we investigated how they are influenced by the earthquake magnitude, hypocentral distance and the focal depth. Also the correlation of the duration and its related parameters with JMA instrumental seismic intensity were conducted.

Figure 5 presents a plot of the duration of each component (E-W, N-S, and U-D) versus earthquake magnitude M_J. There is a consistent correlation with duration increasing gradually as earthquake magnitude M_J increases. This overall trend for the duration is consistent with the previous study (Dobry *et al.* [5]). We can see from Figure 5, as Trifunac and Brady [1] indicated that the average duration of vertical ground motion is longer than the average duration of horizontal ground motion by several to about 10 sec, a similar tendency is true of the present study. A plot of all data for the total power versus earthquake magnitude M_J are shown Figure 5. As seen in Figure 5, the scatter is wide, as is expected. The large scatter of data on the total power is appreciable and no significant trend with M_J is apparent. Additionally the total power of horizontal components is greater than vertical component. Figure 7 shows all data for rms amplitude plotted versus earthquake magnitude M_J. From Figure 7, rms amplitude of vertical component is smaller than horizontal components and no obvious correlation of rms amplitude with M_J is also apparent. From Figure 6 and Figure 7, the total power and rms amplitude depend not only on earthquake magnitude M_J but also on other factors. Kamiyama [2] indicated that the dependence of the total power on earthquake magnitude M_J is greater than rms amplitude. Nevertheless, the similarity in earthquake magnitude M_J dependence trends for the total power and rms amplitude are shown in the present study.

Figure 8 presents a plot of the duration versus hypocentral distance. With increasing hypocentral distance, the duration increases in Figure 8. Records from other earthquakes were also studied to examine duration characteristics (Shoji *et al.* [8]). This general tendency is consistent with the present study. Again, the duration of the vertical component of ground motion is on the average several seconds longer than the duration of the horizontal components. A plot of the total power and rms amplitude versus hypocentral distance are shown in Figure 9 and Figure 10. A comparison between Figure 8 and 9 shows the major difference between the duration and the total power. This trend is essentially the same for the total power in Figure 9 and the rms amplitude in Figure 10. It is clear that the duration demonstrates the opposite tendency whereas the decrease of the total power and rms amplitude with increasing hypocentral distance.

Figure 11 shows the duration versus focal depth. A plot of the total power and rms amplitude versus focal depth are shown Figure 12 and Figure 13. It is seen from Figure from 11 to 13 that there is considerably more scatter for the total power and rms amplitude than for the duration. From Figure 12 and Figure 13, it is suggested that the focal depth has little effect on the total power and rms amplitude. As Kamiyama [2] have already pointed out, the duration is going to get larger and larger with decreasing the focal depth, a similar thing is true of the present study. A plausible explanation for this fact could be that the longer duration has reference to the surface wave generated by the shallow depth of earthquake sources.

The seismic intensity might be more appropriate on account of its overall effect on earthquake damage. The seismic intensity has been determined instrumentally using earthquake motion records so that it represents a reliable engineering parameter. Figure 14 presents the duration versus the JMA instrumental seismic intensity. In Figure 14, The indicated tendency for the duration to decrease with increasing intensity level (Trifunac and Brady [1]), a similar tendency was found in the present study, while the duration of earthquake ground motions shows much lager scatter. The general trend, with increasing instrumental seismic intensity the duration decreases, was presented. A plot of the total power versus JMA instrumental seismic intensity is shown Figure 15. There is a good correlation between the total power and JMA instrumental seismic intensity. Also Figure 16 shows rms amplitude versus JMA instrumental seismic intensity. The generally consistent correlation between rms amplitude and JMA instrumental seismic intensity was shown in Figure 16. Since rms amplitude is intimately associated with the fault model of earthquakes and is a stable parameter according to McGuire and Hanks [9]. A good correlation of peak ground acceleration PGA with rms amplitude was also presented using other earthquake records (Kamiyama [2], Shoji *et al.* [8]). These relationships are quite useful to estimate PGA and the JMA instrumental seismic intensity using the fault model.

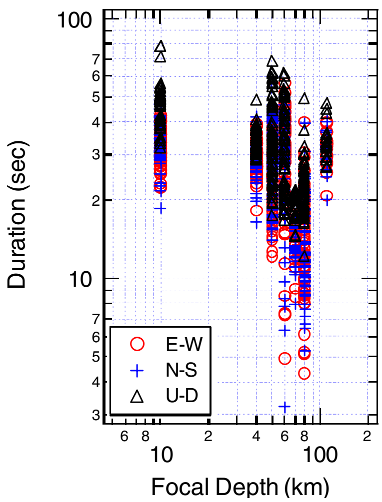

Figure 11: Correlation between the duration and focal depth

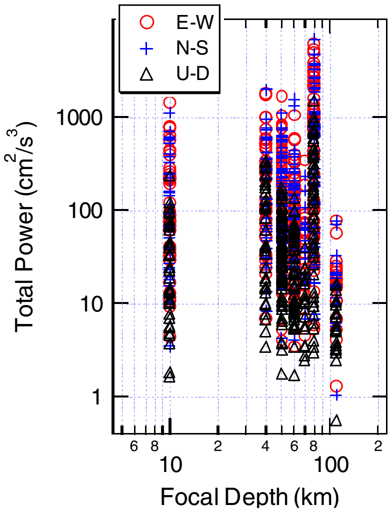

Figure 12: Correlation between the total power and focal depth

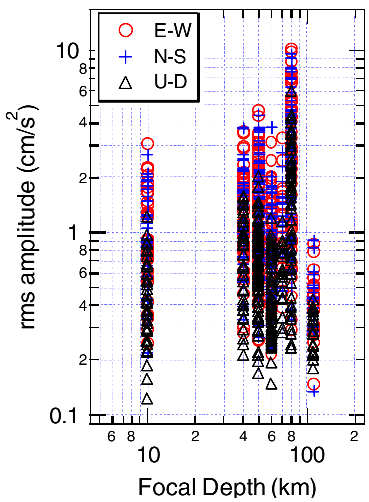

Figure 13: Correlation between rms amplitude and focal depth

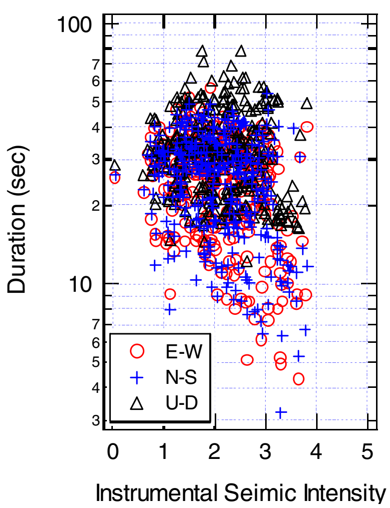

Figure 14: Correlation of the duration with JMA instrumental intensity

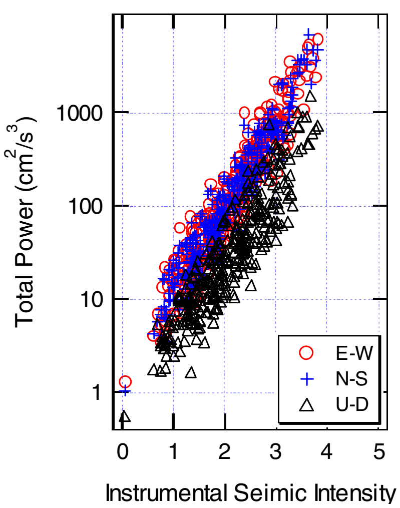

Figure 15: Correlation of the total power with JMA instrumental intensity

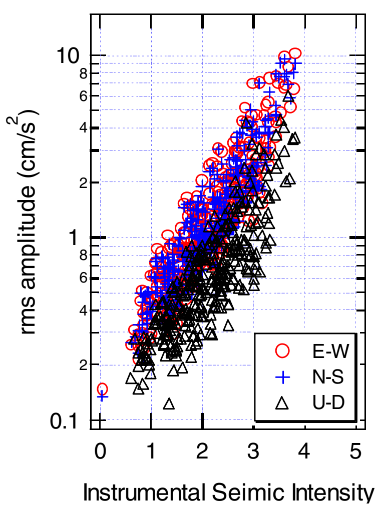

Figure 16: Correlation of rms amplitude with JMA instrumental intensity

Site-dependency and event-dependency

As described earlier, a simple statistical technique was performed by using the earthquake ground motion records of Small-Titan, analyzing the site-dependency and the event-dependency. The duration and its related parameters were adopted as representative parameter of the duration characteristics of earthquake ground motions in this paper.

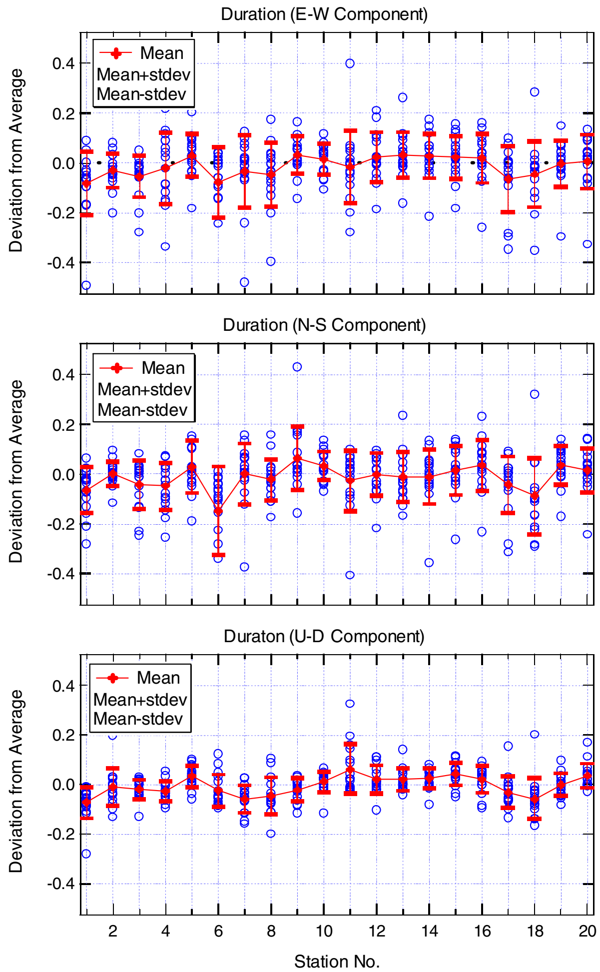

Figure 17: Site-dependency and event-dependency for the duration

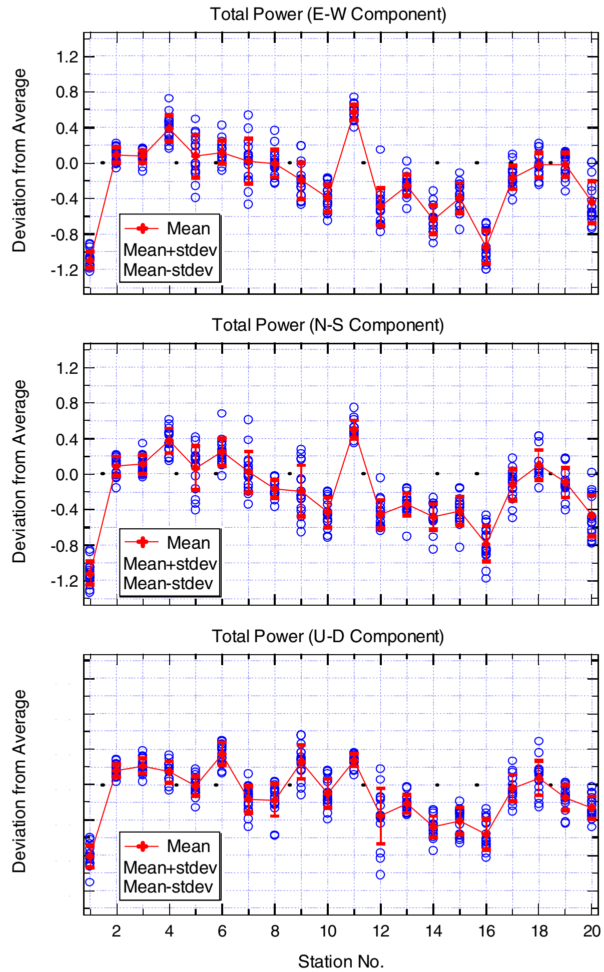

Figure 18: Site-dependency and event-dependency for the total power

Figure 17 shows the site-dependency and the event-dependency for the duration of all three components (E-W, N-S, and U-D). We can see in Figure 17, the difference of the duration is not only site-dependent but also event-dependent. According to our definition of local site effects described earlier, it is found in Figure 17 that the event-dependency for the duration is greater than the site-dependency.

A plot of the variability for the total power is shown in Figure 18. The local site conditions of observation sites exert remarkable effects on the earthquake ground motions. In Figure 18, therefore, the total power varies significantly reflecting the local site conditions. In contrast to the duration in Figure 17, the difference of the total power at each site exceeds the variability at each event. In addition, the variability for the total power shows opposite trend against the duration.

The site-dependent and the event-dependent variability for rms amplitude are shown in Figure 19. As can be seen from Figure 19, rms amplitude is affected by local site conditions, and strong site-dependency is found. By comparing Figure 18 and Figure 19, the total power and rms amplitude follow a similar site-dependent trend. It appears that the total power and rms amplitude tend to be consistent, with regard to the site-dependency and the event-dependency. On the contrary, a plot for the duration in Figure 17 looks nothing like the total power and rms amplitude.

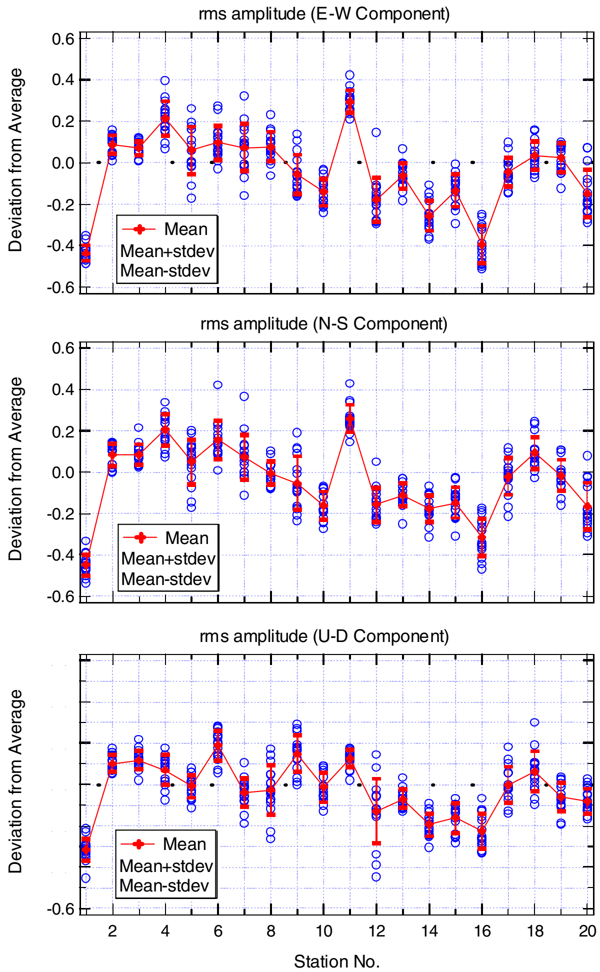

Figure 19: Site-dependency and event-dependency for rms amplitude

DISCUSSION

The duration and amplitude characteristics of earthquake ground motions were studied using the high-quality, three-component digital records of Small-Titan.

In Figure 17, a close look at the site-dependency for the duration of all three components shows weak site-dependency. By comparing the variability of all three components, we found the similarity in site-dependence trends among all three components. However, the event-dependency of vertical component is generally smaller than those of horizontal components. It is indicated that the duration of horizontal components are strongly influenced by the event-dependent factors, such as the earthquake magnitude, hypocentral distance and the focal depth.

For the total power, the site-dependency among all three components is greater than the event-dependency in Figure 18. Obviously, these results made it clear that the difference at each site exceeds the variability at each event. And also, the site-dependency of vertical component is smaller than those of horizontal

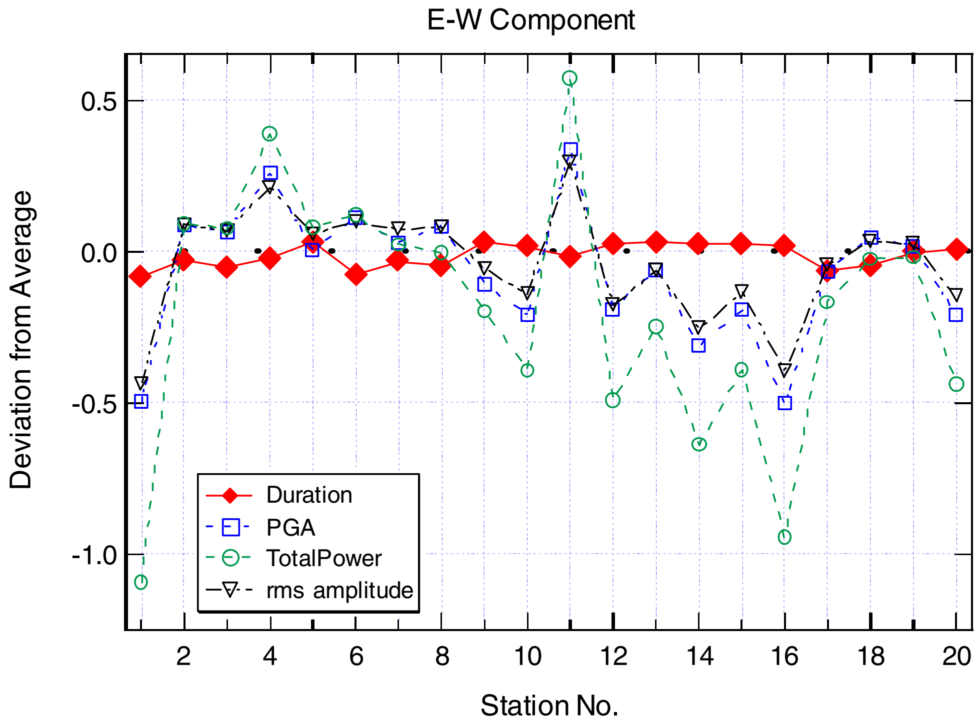

Figure 20: Comparison of the site-dependency for typical ground motion parameters (E-W component)

components, while the similarity in event-dependence trends among all three components is true. Figure 18 suggested that the dependence of the total power on earthquake factors, such as the earthquake magnitude, hypocentral distance and the focal depth, seems to be constant in spite of strong site-dependency for the total power.

In comparison between Figure 18 and Figure 19, no significant difference between the total power and rms amplitude was shown. For the site-dependency and the event-dependency, there is a fairy good agreement between the total power and rms amplitude. After all, for the total power and rms amplitude, the difference at each site exceeds the variability at each event and strong site-dependency was found.

As described previously, Shoji *et al.* [3] discussed the variability of ground motion parameter, such as JMA instrumental seismic intensity, peak ground acceleration, peak ground velocity and the product of the peak acceleration and the peak velocity. They suggested that the difference at each site exceeds the variability at each event. The site-dependency and the event-dependency for these parameters showed the same tendency. For the same array and the same data, the same technique was applied to the duration and its related parameters in this paper. As the result, the site-dependency and the event-dependency for theses parameters were consistent with those for the total power and rms amplitude in the present study. Namely, the total power, rms amplitude, JMA instrumental seismic intensity, peak ground acceleration, peak ground velocity and the product of the peak acceleration and the peak velocity indicate the same trends regarding the site-dependency and the event-dependency.

Among various ground motion parameters, such as JMA instrumental seismic intensity, peak ground acceleration, and the duration, these parameters would be divided into two groups regarding the site-dependency and the event-dependency. One is the ground motion parameters based on "amplitude", such

as JMA instrumental seismic intensity, peak ground acceleration, the total power and rms amplitude, and the other based on "duration", such as the duration. With regard to the site-dependency and the event-dependency, the duration is a reciprocal parameter against other parameters based on "amplitude".
In order to reveal the significant difference between ground motion parameter based on "amplitude" and other parameters based on "duration", the site-dependency of E-W component for typical parameters were shown in Figure 20. Peak ground acceleration PGA in Figure 20 was reproduced from Shoji *et al.* [3]. The site-dependency for the total power, rms amplitude and PGA indicated the same trends. Special emphasis should be placed here on the fact that the site-dependency for the duration shows not only the weak site-dependent trend but also reversed plus and minus against other parameters at each stations.
This paper indicated that the duration and amplitude characteristics of earthquake ground motions suffer a reciprocal effect due to the earthquake magnitude, hypocentral distance, the focal depth and the local site conditions.

CONCLUSIONS

This paper dealt with the duration and its related parameters were adopted as representative parameter of the duration characteristics of earthquake ground motions. It was investigated how they are influenced by the earthquake magnitude M_J, hypocentral distance and the focal depth. In addition, the correlation the duration and its related parameters with JMA instrumental seismic intensity were shown in this paper. Moreover, a statistical technique applied to the duration and its related parameters to detect the site-dependency and event-dependency of these parameters. By comparing the site-dependency and event-dependency for the duration and its related parameters, we discussed the duration and amplitude characteristics with emphasis on the local site effects.
The concluding remarks are summarized as follows:
(1) It was investigated how they are influenced by the earthquake magnitude M_J, hypocentral distance and the focal depth. Also, correlations of the duration and its related parameters with the JMA instrumental seismic intensity were shown. The average and overall trends of the duration and its related parameters were presented in this study.
(2) According to our definition of local site effects, the event-dependency for the duration is greater than the site-dependency. In contrast to the duration, the site-dependency for the total power is greater than the event-dependency. And also, the site-dependency for the total power and rms amplitude indicated essentially the same trends.
(3) Among various ground motion parameters, such as JMA instrumental seismic intensity, peak ground acceleration, and the duration, these parameters would be divided into two groups regarding the site-dependency and the event-dependency. One is the ground motion parameters based on "amplitude", such as JMA instrumental seismic intensity, peak ground acceleration, the total power and rms amplitude, and the other based on "duration", such as the duration. With regard to the site-dependency and the event-dependency, the duration is a reciprocal parameter against other parameters based on "amplitude". Moreover, this paper suggested that the duration and amplitude characteristics of earthquake ground motions suffer a reciprocal effect due to the earthquake magnitude, hypocentral distance, the focal depth and the local site conditions
In view of the results, the duration is not less important than the maximum amplitude and frequency content in earthquake engineering. Furthermore, this paper provided meaningful information of input motion available to earthquake-resistant design.

ACKNOWLEDGMENTS

The use of the data from Small-Titan (Strong Motion Array of Local Lots by the Tohoku Institute of Technology Area Network) is greatly appreciated.

REFERENCES

1. Trifunac M. D. and Brady, A. G., "A study on the duration of strong earthquake ground motion," *Bull. Seis. Soc. Am.*, Vol. 65, No. 3, 1975, pp. 581-626,
2. Kamiyama, M., "A statistical analysis of duration and its related parameters with emphasis on local soil conditions," *JSCE*, No. 350/I-2, 1984, pp. 271-280 (in Japanese).
3. Shoji, Y., Kamiyama, M. and Matsukawa, T., "Estimates of local site effects using observed records of array observation system "Small-Titan"", *Proc. of the 11th Japan Earthquake Engineering Symposium*, 2002, CD-ROM: 1-8 (in Japanese).
4. Shoji, Y. and Kamiyama, M., "A high-density array observation system, Small-Titan: an introduction and it's strong-motion records", *Proc. of the 12th World Conf. on Earthquake Eng.*, 2000; CD-ROM: 1-8.
5. Dobry, R., Idriss I. M. and E. Ng, "Duration characteristics of horizontal components of strong-motion earthquake records," *Bull. Seis. Soc. Am.*, Vol. 68, No. 5, 1978, pp. 1487-1520.
6. Aki, K., "Local site effects on strong ground motion", *Proc. Earthquake Eng. Soil Dyn.* 1988; II, pp. 103-155.
7. Field, E. H. "Accounting for site effects in probabilistic seismic hazard analyses of southern California: Overview of the SCEC phase III report", *Bull. Seism. Soc. Am.*, Vol. 90, No. 6B, 2000; 85: S1-S31.
8. Shoji, Y., Tanii K. and Kamiyama, M., "A study on the duration and amplitude characteristics of earthquake ground motions", *Proc. of the 11th ICSDEE/3rd ICEGE*, 2004, Vol. 2, pp. 157-166.
9. McGuire R. K. and Hanks T., "Rms acceleration and spectral amplitude of strong ground motion during the San Fernando, California earthquake," *Bull. Seis. Soc. Am.*, Vol. 70, No. 5, 1980, pp. 1907-1919,.