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STRONG MOTION RECORDS FROM THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE

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ABSTRACT: Owing to dense strong motion networks in Japan, many strong motion records were obtained from the 2011 Off the Pacific Coast of Tohoku earthquake (Mw 9.0). More than 2,000 records are available. This paper describes the outline of strong motion networks in Japan and the observed records. Overall characteristics of ground motion from the earthquake are also discussed.

Key Words: strong motion record, The 2011 Off the Pacific Coast of Tohoku earthquake

INTRODUCTION

The gigantic earthquake that hit the Pacific coast of the Tohoku region, northeastern Japan, on March 11, 2011, (the 2011 Off the Pacific Coast of Tohoku earthquake) registered a moment magnitude (Mw) of 9.0, the largest ever recorded in Japan. To understand the characteristics of strong ground motion from such a gigantic earthquake is of great significance in preparing measures to reduce damage from a similar event in the future. No thorough examinations, however, have been done for the characteristics of ground motion from gigantic earthquakes. This is because that such a gigantic earthquake rarely occurs, and their strong motion records have been only limited.

Many strong motion records were obtained from the March 11 earthquake owing to implementation of dense strong motion observation in Japan. These records will provide valuable information to reveal ground motion characteristics of gigantic earthquakes. This paper describes the outline of strong motion networks in Japan and the observed records from the earthquake. Then, overall characteristics of ground motion from the earthquake are discussed.

STRONG-MOTION OBSERVATION NETWORKS IN JAPAN

Strong motion observation of Japan started in 1953. After that, the number of the strong-motion sites was increasing. During the 1995 Kobe earthquake, however, few records were observed in the disastrous belt zone where many buildings and infra-structures were totally collapsed. After the earthquake, importance of strong-motion observation has been strongly recognized. As a result, many nation-wide and local strong-motion observation networks were constructed. In total, more than 10,000 strong motion sites on ground are maintained by different institutions (Midorikawa, 2005a). The main objective of the networks constructed is classified into two types; one is basic research to obtain the time history data for analysis, and another is disaster management to obtain the seismic intensity data for quick and efficient emergency response decisions.

The nation-wide networks for research are such as K-NET (about 1,000 sites) and KiK-net (about 700 sites) by National Research Institute for Earth Science and Disaster Prevention (NIED) and PARI-net (about 70 sites) by Port and Airport Research Institute. The other research institutes such as Building Research Institute (BRI), National Institute for Land and Infrastructure Management, National Institute for Rural Engineering, and Central Research Institute of Electric Power Industry, have also their networks.

The networks for disaster management are such as JMA-net (about 600 sites) by Japan Meteorological Agency, Prefectures-net (about 2,800 sites) by each prefectural office and MLIT-net (about 700 sites) by Ministry of Land, Infrastructure and Transport. The Prefecture-net was established with initiative of Fire and Disaster Management Agency, and the instrument to measure the seismic intensity was installed at almost all the municipalities in Japan. Figure 1 shows locations of the sites for the nation-wide networks. In addition, lifeline companies such as Japan Highway Public Corporation, Japan Railway Companies, and Nippon Telegraph and Telephone Corporation, have also their nation-wide networks for disaster management. For example, the network by Japan Highway Public Corporation consists of about 300 sites.

The local networks have been also constructed by universities, local governments and private companies. In Sendai, Miyagi Prefecture, which is the largest city in the Tohoku region, two local networks have been implemented by Tohoku University and Tohoku Institute of Technology, respectively (Ohno et al., 2011; Kamiyama, 2011). In the Tokyo Metropolitan area, the high-density seismic observation network of about 250 sites, called MeSO-net, has been installed at an interval

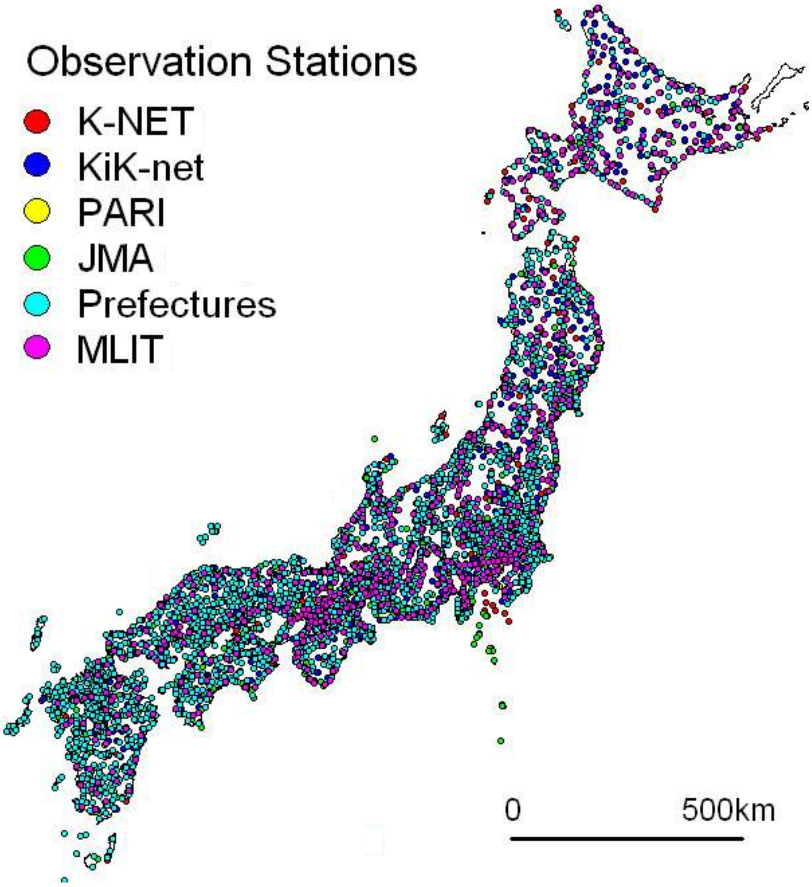


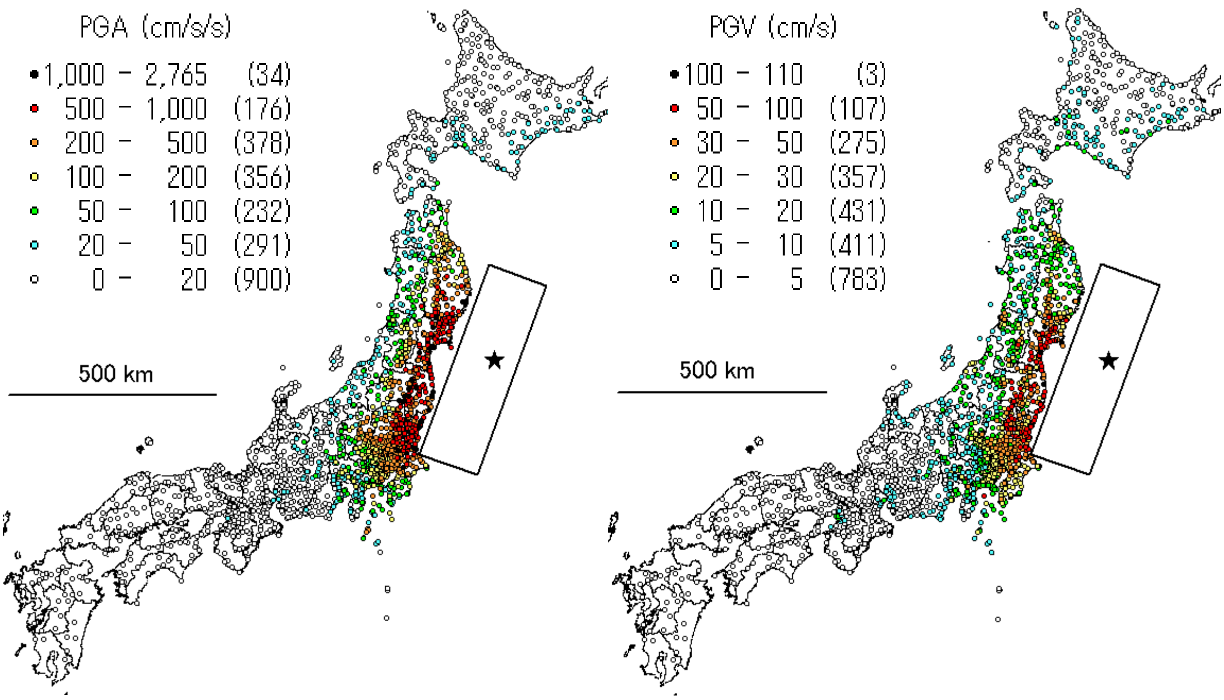
Fig. 1 Distribution of strong motion sites of nation-wide networks in Japan

distance of about 5 km by Earthquake Research Institute (ERI), University of Tokyo (Sakai and Hirata, 2009). Although the main objective of this network is not strong motion observation but to monitor the seismic activity of Tokyo, the full-scale accelerations of the observation system are 1.5 g and 0.5 g for horizontal and vertical component, respectively. ERI has also more than 60 strong motion sites in the Tokai and Kanto regions (Kudo, 1999). The other universities such as Tokyo Institute of Technology, Hokkaido Univ., Nagoya Univ. and Kyoto Univ., have also their local networks.

Local governments have also their network for disaster management. The city of Yokohama developed the dense network which consists of 150 sites with spacing of about 2 km. Using the ground motion data, the damage assessment system works immediately after the event (Midorikawa, 2005b). The other major cities have the similar but smaller system. Lifeline companies such as Tokyo Gas, Osaka Gas, and Toho Gas Companies, have also the network for the damage assessment system.

OUTLINE OF OBSERVED STRONG MOTION RECORDS

Many strong motion records were obtained from the March 11 earthquake. About 1,200 K-NET and KiK-net records were made available soon after the earthquake (NIED, 2011). JMA released about 40 records as the sample data on the web site (JMA, 2011), and the additional 400 records are going to be released. JMA is also compiling several hundreds of records from the Prefectures-network. About 150 records from the MLIT network have been released (MLIT, 2011). BRI and PARI also released their records (BRI, 2011; PARI, 2011). We tentatively collected the records from the K-NET, KiK-net (at surface), JMA, Prefectures, MLIT, PARI and BRI networks. The total number of the collected records is about 2,400. Figure 2 shows the distribution of peak horizontal acceleration and velocity. The peak horizontal accelerations higher than 500 cm/s^2 and 1000 cm/s^2 are observed at 210 and 34 sites, respectively. The peak horizontal velocities higher than 50 cm/s and 100 cm/s are at 111 and 3 sites, respectively.



(a) Peak horizontal acceleration (b) Peak horizontal velocity

Fig. 2 Distributions of peak horizontal acceleration and velocity of observed strong motion records

Among the records, the maximum peak acceleration observed is about 2.8 g at K-NET Tsukidate, Miyagi prefecture. The acceleration time history of the K-NET Tsukidate record is shown in Fig. 3. The waveform is composed of two distinct phases producing long duration of strong shaking. In the second phase, pulse-like high accelerations appear in the north-south and vertical components. Such high acceleration pulses are not observed at the surrounding sites, as shown in Fig. 4. Figure 5 shows the orbit of the high-pass-filtered displacement in the vertical (NS-UD) plane, showing an arc-like shape. This suggests that the foundation of the instrument caused combination of sway and rocking motions. The high acceleration at K-NET Tsukidate may be due to partial uplifting of the foundation of the instrument, as has been discussed by Motosaka and Tsamba (2011), and may not necessarily indicate actual ground acceleration.

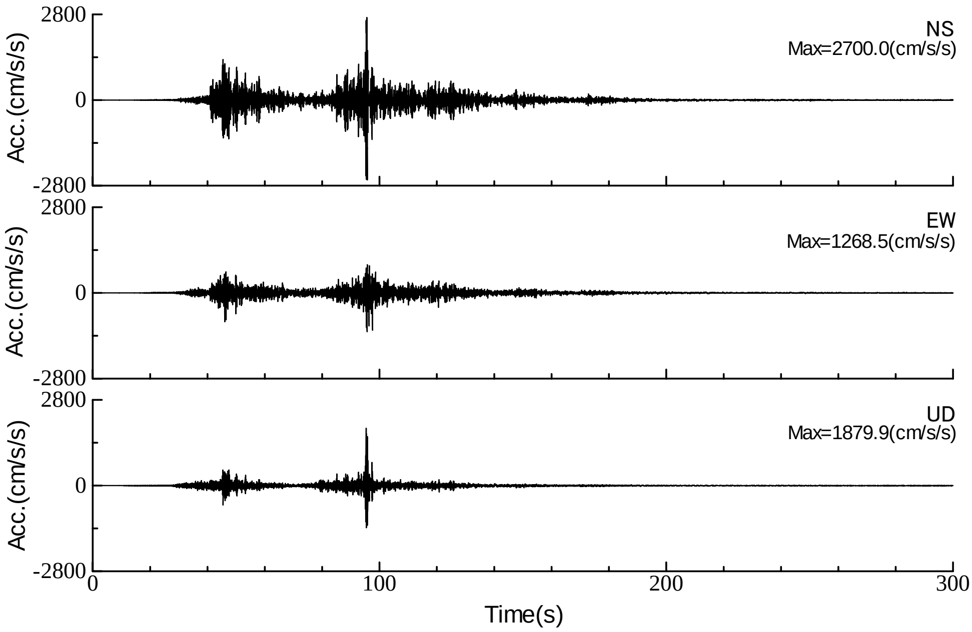


Fig. 3 Acceleration time history of record at K-NET Tsukidate

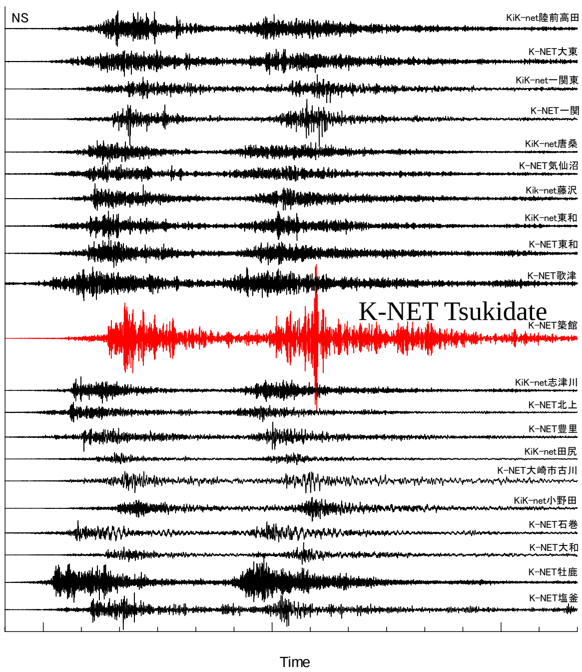


Fig. 4 Past-up of acceleration time histories at K-NET Tsukidate and its surrounding sites

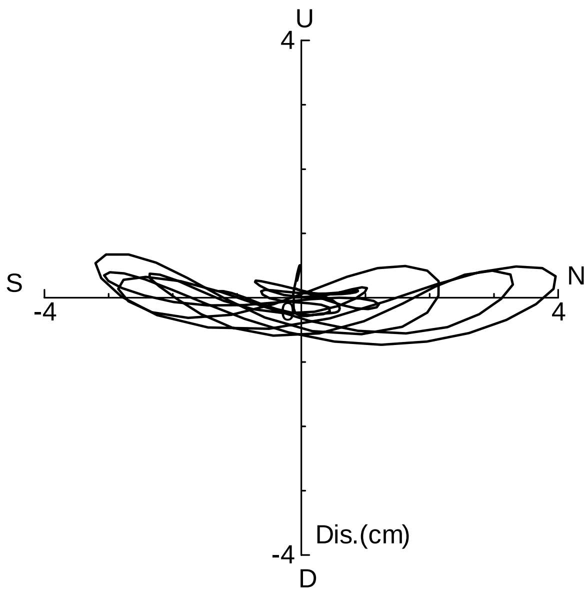


Fig. 5 Orbit of displacement of K-NET Tsukidate record in vertical plane

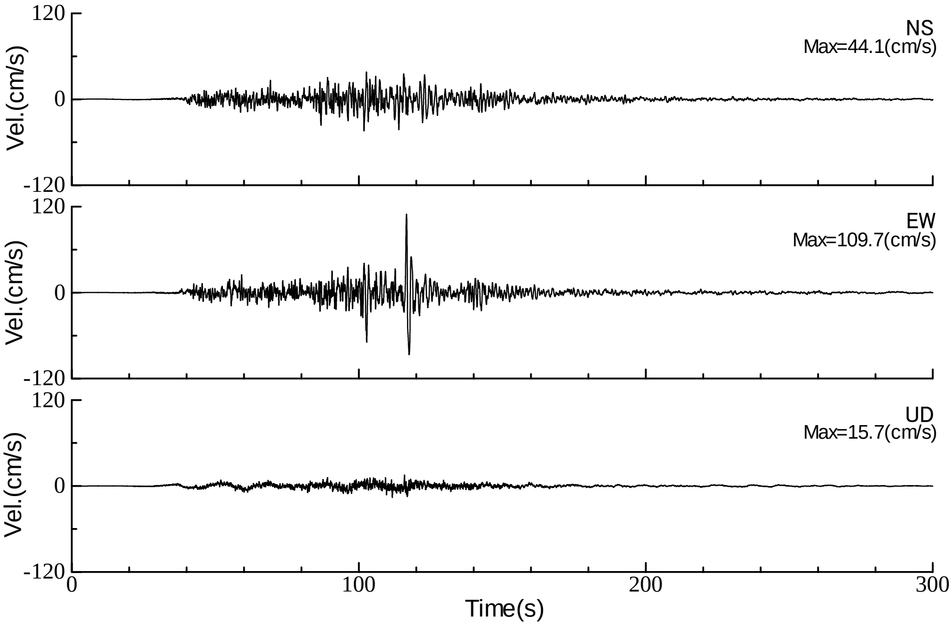


Fig. 6 Velocity time history of record at KiK-net Namie

The maximum peak velocity observed is about 110 cm/s at KiK-net Namie, Fukushima prefecture. The velocity time history of the KiK-net Namie record is shown in Fig. 6. The duration of strong shaking is also long. Unlike the Tsukidate record, however, the waveform is composed of not two distinct phases, but one indistinct phase with a high velocity pulse whose period is about 2 sec. Such a large pulse is also observed at the nearby sites such as Fukushima No.1 nuclear power plant complex. This suggests that the area generating strong ground motion exists near the site.

From the local networks, about 30 records were retrieved in Sendai (Kamiyama, 2011; Ohno et al., 2011). The observed peak horizontal ground acceleration and JMA seismic intensity range 215 to 1853 cm/s^2 and 5.1 to 6.5, respectively. In the Kanto region, more than 200 records were obtained from MeSO-net, and hundreds were from the other local networks, including about 90 records from the Yokohama city network. Figure 7 shows the past-up of the velocity time histories at linearly aligned sites from northeast to southwest in the Kanto region (Tsuno et al., 2011).

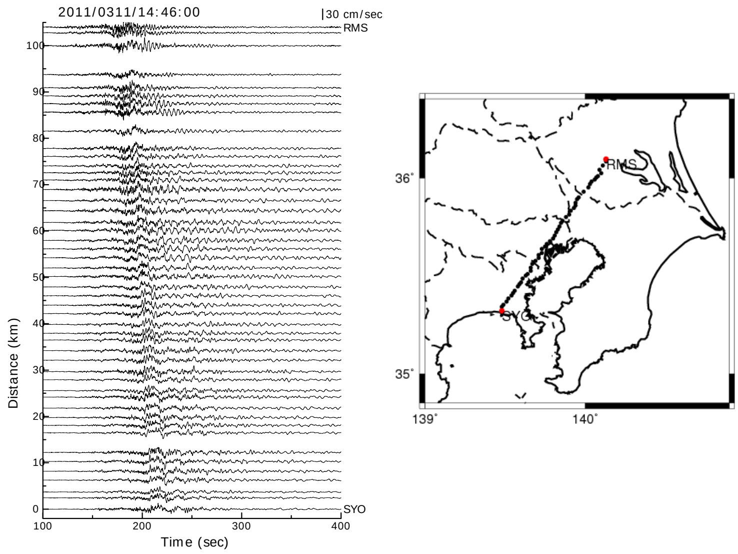


Fig. 7 Past-up of velocity time histories at linearly aligned sites from northeast to southwest in the Kanto region (Tsuno et al., 2011)

GENERAL CHARACTERISTICS OF OBSERVED GROUND MOTION

Figure 8 shows attenuations of peak horizontal acceleration and velocity. In calculation of the shortest distance from the fault, the fault plane by Koketsu et al.(2011) shown in Fig. 1 is used. The observed data are widely dispersed with distance, but the peak accelerations and velocities generally are 200 to 1,000 cm/s^2 and 20 to 80 cm/s for the distance of 50 kilometers, 100 to 500 cm/s^2 and 10 to 50 cm/s for 100 km, and 20 to 150 cm/s^2 and 3 to 20 cm/s for 200 km, respectively. The figure also shows attenuation curves obtained from attenuation relationships by Si and Midorikawa (1999) for earthquakes with a magnitude of 8.0, 8.5 and 9.0, respectively. Although the inclination of attenuation of the observed data seems slightly steeper than the attenuation curves, on the average, it appears to be smaller than the curve for M9.0 and come between curves for M8.0 and M8.5.

As mentioned earlier, high accelerations over 1000 cm/s^2 are observed at 34 sites, while peak velocities over 100 cm/s are only at 3 sites. This may suggest that high frequency contents tend to be dominant in the earthquake. To check the frequency contents of the records, the ratio of peak horizontal acceleration to peak horizontal velocity is calculated. Figure 9 shows the ratio with fault distance. The ratio ranges 10 to 30 at shorter distance, and the values are larger in comparison with the results in the previous study (Sawada et al., 1992), suggesting that the earthquake may generate rich high frequency motion. The ratio, however, becomes smaller with distance, and the average values are about 5 and 2 at distances of 200 km and 500 km, respectively. The ratio shows strong distance dependence, probably due to inelastic properties in the propagation path.

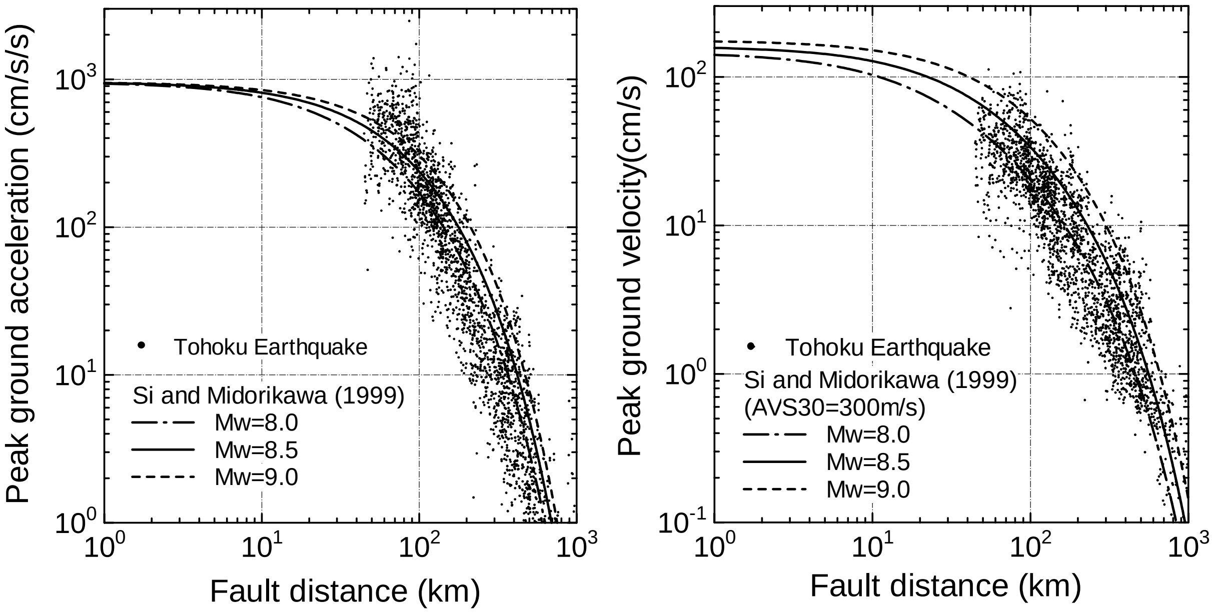


Fig. 8 Attenuation of peak horizontal acceleration (left) and velocity (right)

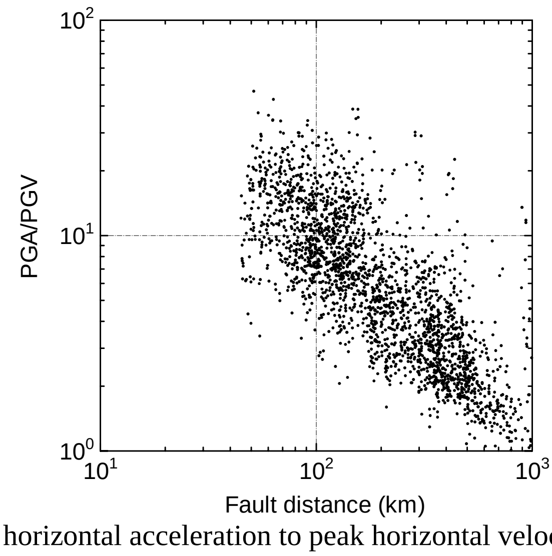
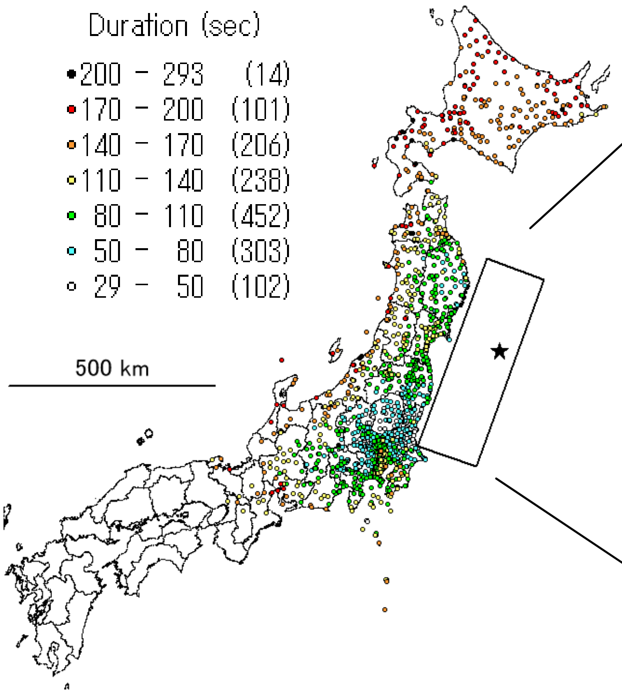


Fig. 9 Ratio of peak horizontal acceleration to peak horizontal velocity with fault distance



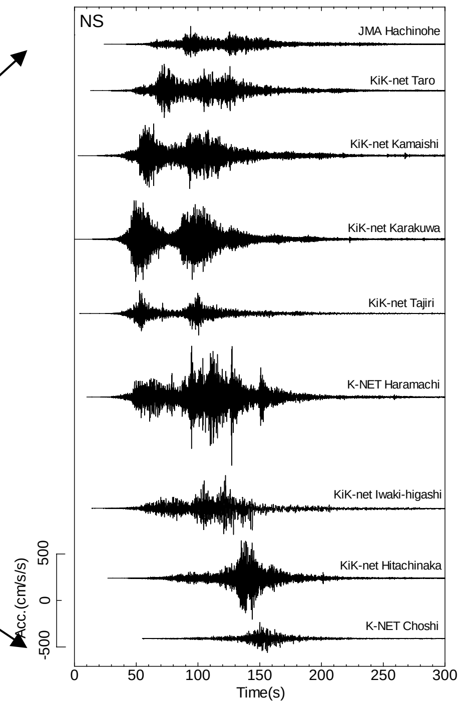


Fig. 10 Distribution of duration

Fig. 11 Past-up of acceleration time histories

The records are also characterized by their long duration. The duration of ground motion is calculated as the time interval between 5 percent and 95 percent of the total power of acceleration. In the calculation, the records with length of longer than 300 sec. are used. The distribution of the duration is shown in Fig. 10. The observed duration is longer than 100 sec. at many sites, although spatial variation of the durations is large. In the area with peak acceleration higher than 200 cm/s^2, the duration ranges 40 to 120 sec. and seems shorter in the southern part of the area. Figure 11 shows the past-up of the acceleration time histories at linearly aligned sites along the Pacific coast from north to south. At the northern sites, the waveform consists of two distinct phases, while it becomes a simple shape at the southern sites, resulting shorter duration in the south. At the middle sites, the waveform seems complex. This is probably due that the rupture mainly propagated to the south while the rupture process is not simple (Furumura et al., 2011).

CONCLUSIONS

Many strong motion records were obtained from the 2011 Off the Pacific Coast of Tohoku earthquake (Mw 9.0), owing to implementation of dense strong motion observation in Japan. More than 2,000 records are available. The high acceleration records are observed at many sites. For example, the records over 1000 cm/s are obtained at more than 30 sites. The attenuations of peak acceleration and velocity are compared with the curves from the previous attenuation relationship. On the average, they appear to be smaller than the curve for M9.0 and come between curves for M8.0 and M8.5. The ratio of peak horizontal acceleration to peak horizontal velocity ranges 10 to 30 at shorter distance. On the records, longer durations are observed. The duration ranges 40 to 120 sec. in the area with peak acceleration higher than 200 cm/s^2, and seems shorter in the southern part of the area, which is probably due to the rupture process of the earthquake. Further investigation of the records will give better understanding of the characteristics of ground motion from gigantic earthquakes.

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REFERENCES

BRI (2011). http://smo.kenken.go.jp/smdb

Furumura, T. et al. (2011). "Strong Ground Motions from the 2011 Off the Pacific Coast of Tohoku, Japan (Mw=9.0) Earthquake Obtained from a Dense Nation-wide Seismic Network." *Landslides*, Vol. 8, No.3, pp.333-338.

JMA (2011). http://www.seisvol.kishou.go.jp/eq/kyoshin/jishin/ index.html

Kamiyama, M. (2011). "*Strong Motion Records of the 2011 Off the Pacific Coast of Tohoku Earthquake from Strong Motion Array Observation System by Tohoku Institute of Technology (Small-Titan).*" Tohoku Branch of the Japanese Geotechnical Society, 35pp. (in Japanese).

Koketsu, K. et al. (2011). "A unified source model for the 2011 Tohoku earthquake." *Earth and Planetary Science Letters*, Vol. 310, No.3-4, pp.480-487.

Kudo, K.(1999). "Strong Motion Observation at Earthquake Research Institute, University of Tokyo." *Seismological Society of Japan Newsletter,* Vol.11, No.3, pp.16-18 (in Japanese).

Midorikawa, S. (2005a). "Strong Motion Networks in Japan – Progress after the 1995 Kobe earthquake –." *Proceedings of the International Symposium on Earthquake Engineering (ISEE Kobe 2005),* Vol. 1, pp.A-91-A-96.

Midorikawa, S. (2005b). "Dense Strong-Motion Array in Yokohama, Japan and Its Use for Disaster Management." *Directions in Strong Motion Instrumentation*, Springer, pp.197-208.

MLIT (2011). http://www.nilim.go.jp/lab/rdg/index.htm

Motosaka, M. and Tsamba, T. (2011). "Investigation of High Acceleration Records at K-NET Tsukidate Station During the 2011 Off the Pacific Coast of Tohoku Earthquake." *Proceedings of the 8th Annual Meeting of Japan Association for Earthquake Engineering*, pp.24-25.

NIED (2011). http://www.kyoshin.bosai.go.jp/index_en.html

Ohno, S. et al. (2011). "Strong motion characteristics in Sendai during the 2011 Off the Pacific Coast of Tohoku earthquake." *Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan*, Vol. B2, pp.189-190 (in Japanese).

PARI (2011). http://www.mlit.go.jp/kowan/kyosin/eq.htm

Sakai, S. and Hirata, N. (2009). "Distribution of the Metropolitan Seismic Observation network." B*ull. Earthq. Res. Inst., Univ. Tokyo,* Vol. 84, pp.57-69 (in Japanese).

Sawada, T., Hirano, K. and Yamamoto, H. (1992). "Relation between maximum amplitude ration (a/v, ad/v2) and spectral parameters of earthquake motions." *Proceedings of the Tenth World Conference on Earthquake Engineering*, Vol. 2, pp.617-622.

Si, H. and Midorikawa, S. (1999). "New Attenuation Relationships for Peak Ground Acceleration and Velocity Considering Effects of Fault Type and Site Condition." *Journal of Structural and Construction Engineering, A.I.J.*, No. 523, pp.63-70 (in Japanese).

Tsuno, S. et al. (2001). "Distributions of Earthquake Ground Motions Observed in and around the Tokyo Metropolitan Area during the 2011 Off the Pacific Coast of Tohoku Earthquake (Mw 9.0)." *Programme and Abstracts, Fall Annual Meeting of Seismological Society of Japan*, P2-18 (in Japanese).