



## **STRONG-MOTION SEISMOGRAPH NETWORK OPERATED BY NIED: K-NET AND KiK-net**

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**ABSTRACT:** After the 1995 Hyogoken-Nanbu earthquake, NIED (National Research Institute for Earth Science and Disaster Prevention) installed the K-NET that uniformly covers all Japan with more than one thousand strong-motion accelerometers on the ground surface. In addition to the K-NET, NIED constructed an uphole/downhole observation network, KiK-net, with approximately 669 stations. Each KiK-net station has a borehole of 100 m or more in depth and strong-motion seismographs have been installed both on the ground surface and at the bottom of the boreholes. The velocity profiles and geological information as well as the observed records are widely accessible on the website.

**Key Words:** Strong-motion, seismograph network, K-NET, KiK-net

### **INTRODUCTION**

During the 1995 Hyogoken-Nanbu (Kobe) earthquake, only few strong motion stations recorded data in the ‘Damaged belt’. Ground motion observation in such a damaged area is a central matter for interpreting the earthquake impact. Based on the lessons from the 1995 Hyogoken-Nanbu earthquake and the measures for the next supposed large earthquakes in/around Japan, the National Research Institute for Earth Science and Disaster Prevention (NIED) constructed two strong motion seismograph networks, K-NET (Kinoshita, 1998) and KiK-net (Aoi et al., 2000). Station distributions for these networks are designed to cover all Japan as uniformly as possible with the instrumentation for most stations being of the same type. The main difference between these two networks is that K-NET is an observation network, which records data only on the free surface, and KiK-net has boreholes with installed sensors located both at the bottom of the borehole and on the surface.

#### **K-NET (Kyoshin NETwork)**

Just after the 1995 Hyogoken-Nanbu earthquake, construction of K-NET began and was completed in just over one year (Kinoshita, 1997). The term K-NET stands for ‘Kyoshin network’ where ‘Kyoshin’ means ‘strong motion’ in Japanese. At its inception, K-NET consisted of 1000 stations

whose average station-to-station distance was about 20 km. All the stations were outfitted with the same type of strong motion accelerometers, K-NET95, which were installed on the free surface. Afterward, some stations were added to K-NET, such as the existing stations within the Kanto-Tokai area or the cable type ocean-bottom strong motion accelerometers at the Sagami Bay. The number of

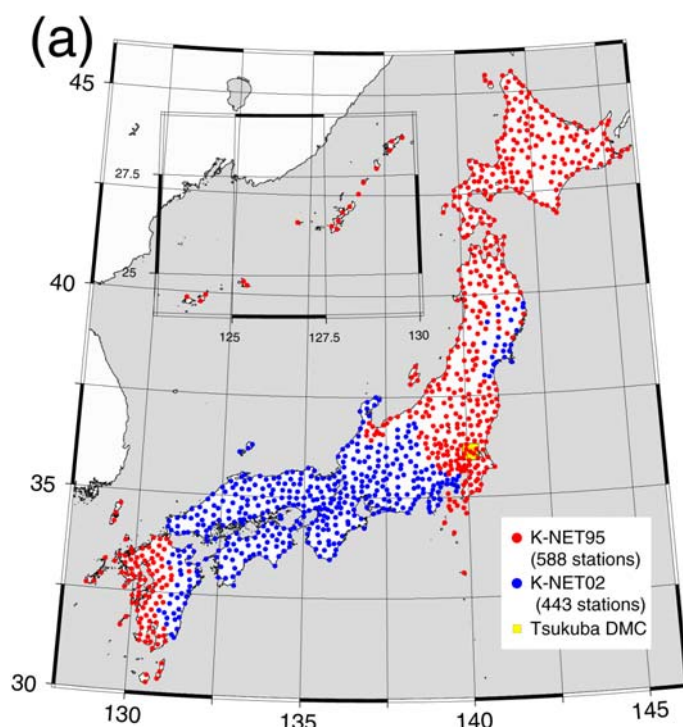


Table 1. Distribution of the KiK-net borehole depth.

Depth [m]	number of stations
100~ 149m	415
150~ 249m	179
250~ 499m	41
500~ 999m	13
1000~1999m	12
2000m~	9
Total	669

Table 2. Stations that have a borehole depth greater than 1000 m.

Station Code	Station Name	Depth [m]
CHBH04	SHIMOHSA	2300
OSKH02	KONOHANA	2008
CHBH16	KAMOGAWA	2003
CHBH10	CHIBA	2000
CHBH11	YOUROU	2000
CHBH12	FUTTSU	2000
GNMH05	ISESAKI	2000
KNGH10	YOKOHAMA	2000
SITH04	TOKOROZAWA	2000
KNGH11	ATSUGI	1800
SITH03	HIDAKA	1800
TCGH06	MOUKA	1648
GIFH09	HASHIMA	1508
OSKH01	TAJIRI	1505
CHBH13	NARITA	1300
MYGH01	SENDAI	1206
YMNH08	NISHINOHARA	1206
GNMH06	TATEBAYASHI	1203
IBRH07	EDOSAKI	1200
IBRH08	TAIYO	1200
AICH04	ANJOU	1055

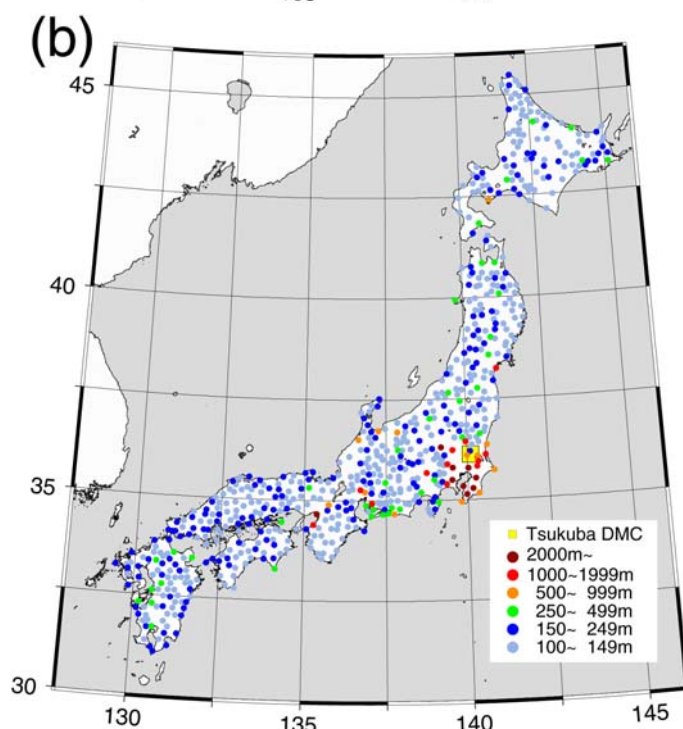


Fig. 1. Distribution of (a) K-NET and (b) KiK-net stations. Red and blue circles in (a) show stations whose outfitted with instruments of K-NET95 and K-NET02, respectively. Color in (b) indicates borehole depth. The yellow square shows the DMC of NIED located in Tsukuba.

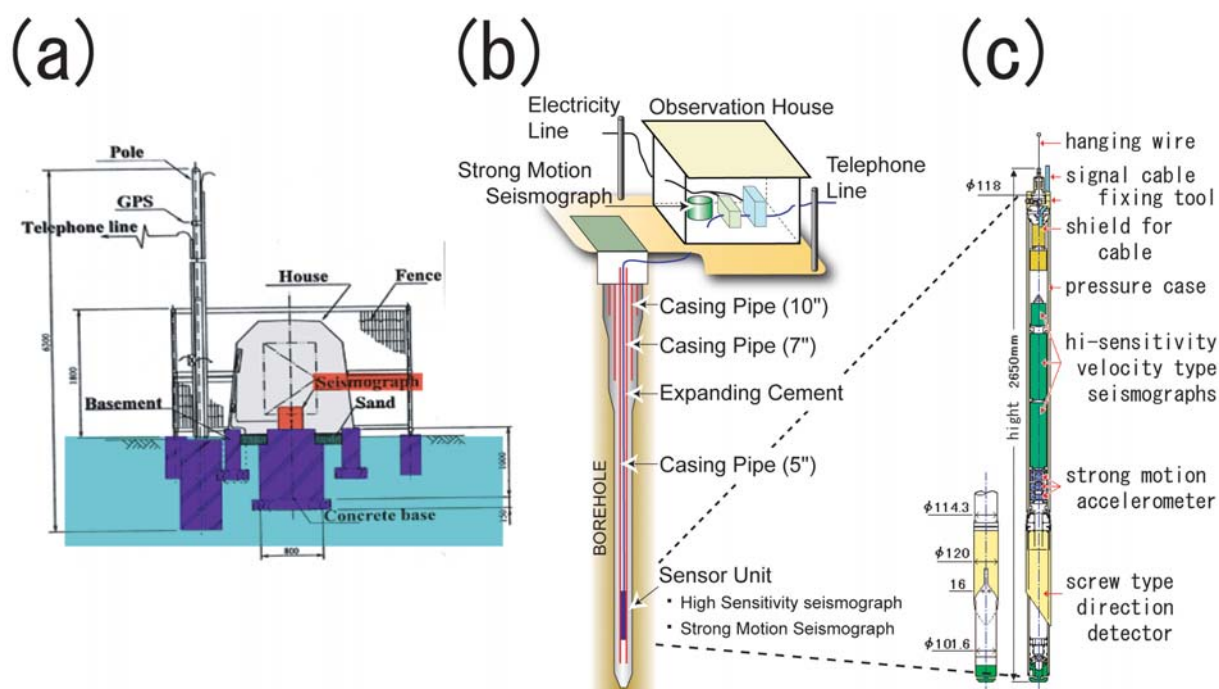


Fig. 2. Observation facility for (a) K-NET and (b) KiK-net. Tri-axis strong-motion accelerometers are installed on the free surface for both networks. For the KiK-net, a strong-motion accelerometer is also installed at the bottom of the borehole stored in a pressure-resistant tube made of stainless steel together with the high-sensitivity seismographs (Hi-net). (c) shows a downhole instrument for KiK-net.

stations currently is 1030, and this amount varies as new stations are added or old stations are taken off-line.

### KiK-net (Kiban Kyoshin network)

The Japanese government established 'the Headquarters for Earthquake Research Promotion' on July 18, 1995, and the 'Fundamental Survey and Observation for Earthquake Research' plan was developed under their direction. In short, this plan is called KIBAN, which is a Japanese word meaning fundamental or infrastructure. The main part of the 'Kiban' project consists of the total observation network (Okada et al., 2004), which is composed of several different types of observation networks: the high sensitivity seismic network (Hi-net; Obara et al., 2002), the strong motion observation network (KiK-net; Kiban Kyoshin network, Aoi et al., 2000), the broadband seismic observation network (F-net, Fukuyama et al., 1996), and the continuous GPS observation network (GEONET; Geographical Survey Institute, 1998). Each KiK-net station has an observation borehole of more than 100 m deep. Strong motion seismographs are installed on the ground surface and also at the bottom of the observation boreholes together with high sensitivity velocity seismographs for Hi-net.

One of the characteristics of these two networks is that they are open data networks. Strong motion records are available through the Internet several hours after the occurrence of an earthquake. Figures for the peak ground motions, waveforms of each station, paste-up waveforms, the geological information and velocity profiles for most stations are also available. The URL is <http://www.k-net.bosai.go.jp> for K-NET and <http://www.kik.bosai.go.jp> for KiK-net.

## LOCATION OF STATIONS AND INSTRUMENTATION

K-NET and KiK-net consist of 1030 and 669 stations, respectively, and uniformly cover almost all Japan (Fig. 1). Most K-NET stations (Fig. 2) are constructed on the grounds of a public facility such as the public office of a municipal government, fire station, school or park and the sensors are installed only on the free surface. This means that the K-NET sites are located near areas where human activity takes place. In many cases, K-NET stations are located on type D ( $180 \text{ m/s} < V_s < 360 \text{ m/s}$ ) or type E ( $V_s < 180 \text{ m/s}$ ) soil as defined by the National Earthquake Hazards Reduction Program (NEHRP; e.g. BSSC, 1997). While the K-NET stations were mainly constructed on sedimentary sites, some of the KiK-net stations (Fig. 2) are located on weathered rock or on thinner sediment (C:  $360 \text{ m/s} < v_s < 760 \text{ m/s}$ ). On average, site conditions of KiK-net are harder than those of K-NET. KiK-net differs from the K-NET in that a pair of strong-motion sensors is installed at each station. One is installed on the ground surface just above the borehole and the other is located at the bottom of the borehole. The horizontal distance of these two sensors is a few meters in most cases. Records from the pair of seismographs enable us to quantitatively evaluate the site effects at each station together with the site information from downhole logging data. At most sites, downhole logging was carried out on the occasion of the boring and the velocity profiles and soil conditions are available on the Internet.

Table 1 shows the distribution of the KiK-net borehole-depth. The borehole was design so that it penetrates the sediment and reaches a type A ( $V_s < 1500 \text{ m/s}$ ) or type B ( $760 < V_s < 1500 \text{ m/s}$ ) rock as defined by NEHRP. The depth of most boreholes is between 100 m to 200 m. At stations in urban areas, which are located on thick sediment within large plains, such as the Kanto plain or Osaka basin,

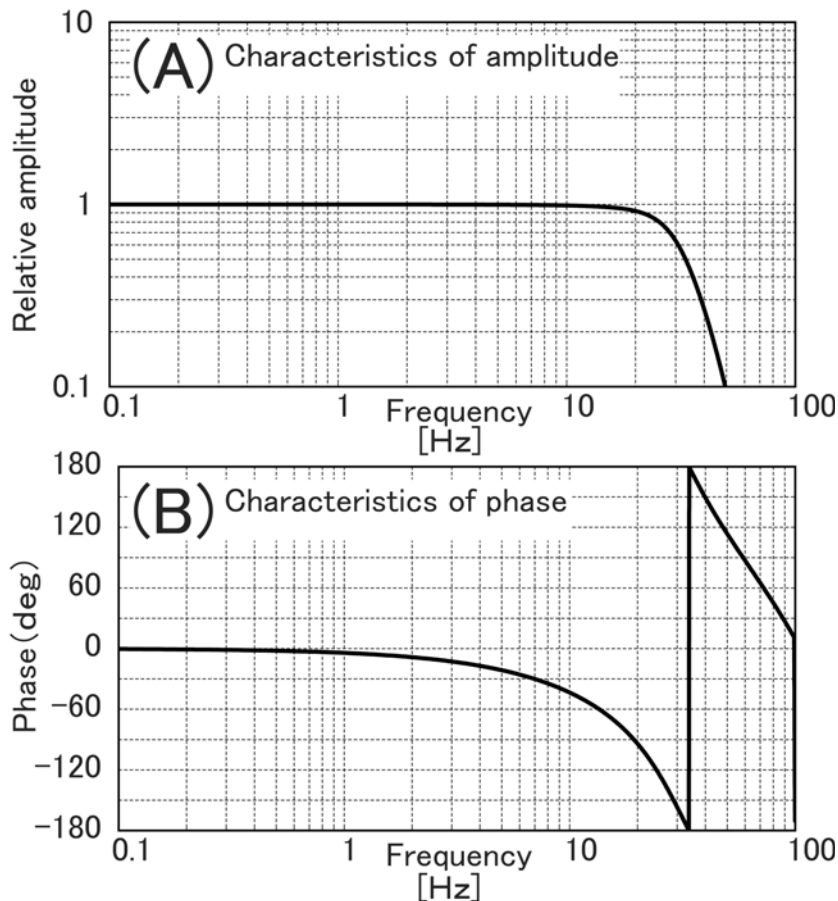


Fig. 3. Total characteristics of the instrument used for the K-NET and KiK-net. (a) and (b) show the amplitude and phase characteristics, respectively. The cut-off frequency of the filter is 30 Hz.

deeper boreholes are constructed and 21 of them are deeper than 1000 m (Table 2).

Instrumentation used for the K-NET and KiK-net is basically the same. The sensor being used is a V403 or V404 tri-axial force-balance accelerometer with a natural frequency of 450 Hz and a damping factor of 0.707, which is manufactured by the Akashi Corporation. The typical sensor gain is 3 V/g (0.306 V/m/s<sup>2</sup>). The data loggers used, K-NET95 (K-NET) and SMAC-MDK (KiK-net), which are also manufactured by the Akashi Corporation, have a 24-bit A/D (effective resolution is at least 18-bit) converter and a maximum measurable acceleration of 2000 gals (cm/s<sup>2</sup>). Waveforms are recorded with a sampling rate of 100 Hz for the K-NET and 200 Hz for the KiK-net. Figure 3 illustrates the amplitude and phase response of the transfer function of the total system.

Ground motion is stored only if the ground motion satisfies the pre-set trigger condition. The event trigger system of the data recorder is controlled using the signals on the surface (K-NET) or downhole seismometer signals (KiK-net). Typically, event recording starts at a threshold level of 2 gals (K-NET) or 0.2-0.4 gals (KiK-net), and ends with a 30 seconds continuous signal of 2 gals or lower (K-NET) or 0.1 gals or lower (K-NET). A minimum recording length of 120 seconds is assured which includes the 15 seconds pre-trigger data. K-NET95 has 8 MB of memory, which can store a total of about 2.5 hours of three component data digitized at a sampling frequency of 100 Hz, and SMAC-MDK has 85 MB of memory that corresponds to about 6.5 hours for 200 Hz of six component data. About 10% of this memory is reserved for large earthquakes. When the 90% memory area used for normal earthquake activity becomes full, ground motion that exceeds a certain threshold, typically 100 gals (K-NET) or 20 gals (KiK-net), is recorded in this reserved memory. The internal clock used for the recording system (1 ppm precision) is automatically calibrated by a GPS signal every hour on the hour with an accuracy of 5 m seconds.

The orientation of horizontal components of downhole seismographs used in the KiK-net have some uncertainty due to difficulties during installation. Orientations are estimated by evaluating correlation of teleseismic waveform data (Shiomi et al., 2003). Sensor orientations may change every time the sensor is re-installed for maintenance or some other reason. The updated orientations are also available through the Internet.

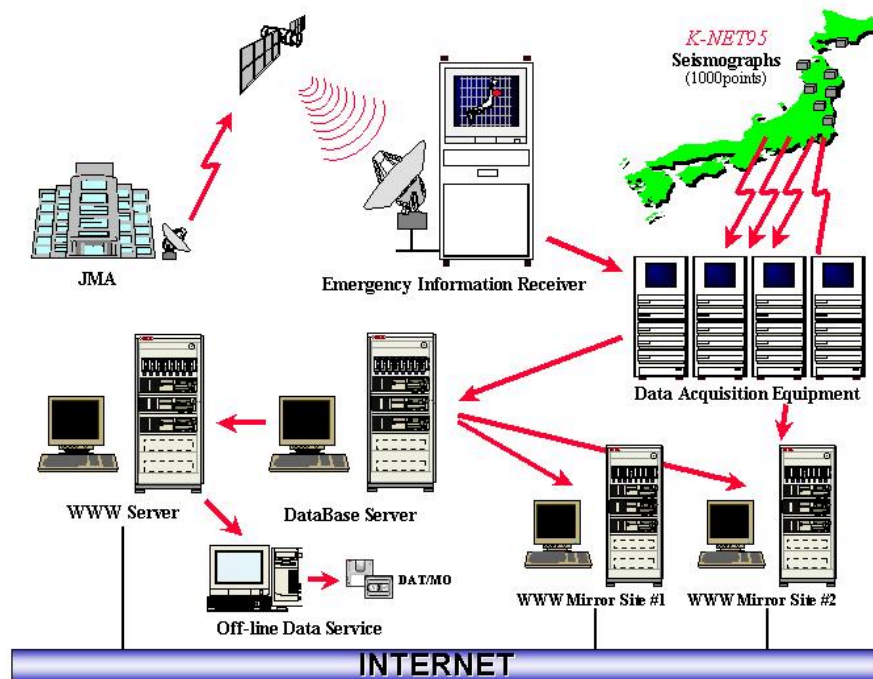


Fig.4 The flow of K-NET data release.



## DATA COLLECTION AND PUBLICATION

The NIED Data Management Center (DMC) located at Tsukuba unifies all observed stations through public telephone lines (Fig. 4). When an earthquake occurs, the JMA (Japan Meteorological Agency) immediately determines the source parameters (location and magnitude) and distributes them through weather satellites. Dial-up operation for the collection of waveform data is triggered when this information is received. The areas where the recorders are expected to be triggered are estimated from the depth and magnitude of the earthquake and the dial-up operations are automatically started.

All digital data collected from earthquakes with a JMA magnitude of more than 3 are manually checked and provided on our website as soon as possible (typically, within a few hours to one day after the earthquake) in the K-NET format. Users can select specific events or stations with a combination of key parameters to download. Station maps, individual waveforms, and a paste-up of waveforms can also be browsed, selected and downloaded. All data and information is also available through an FTP site ([www.k-net.bosai.go.jp](http://www.k-net.bosai.go.jp) for the K-NET and [ftp.kik.bosai.go.jp](http://ftp.kik.bosai.go.jp) for the KiK-net).

## EXAMPLE OF DATA

We would like to introduce two large earthquakes as examples of typical data recorded by our

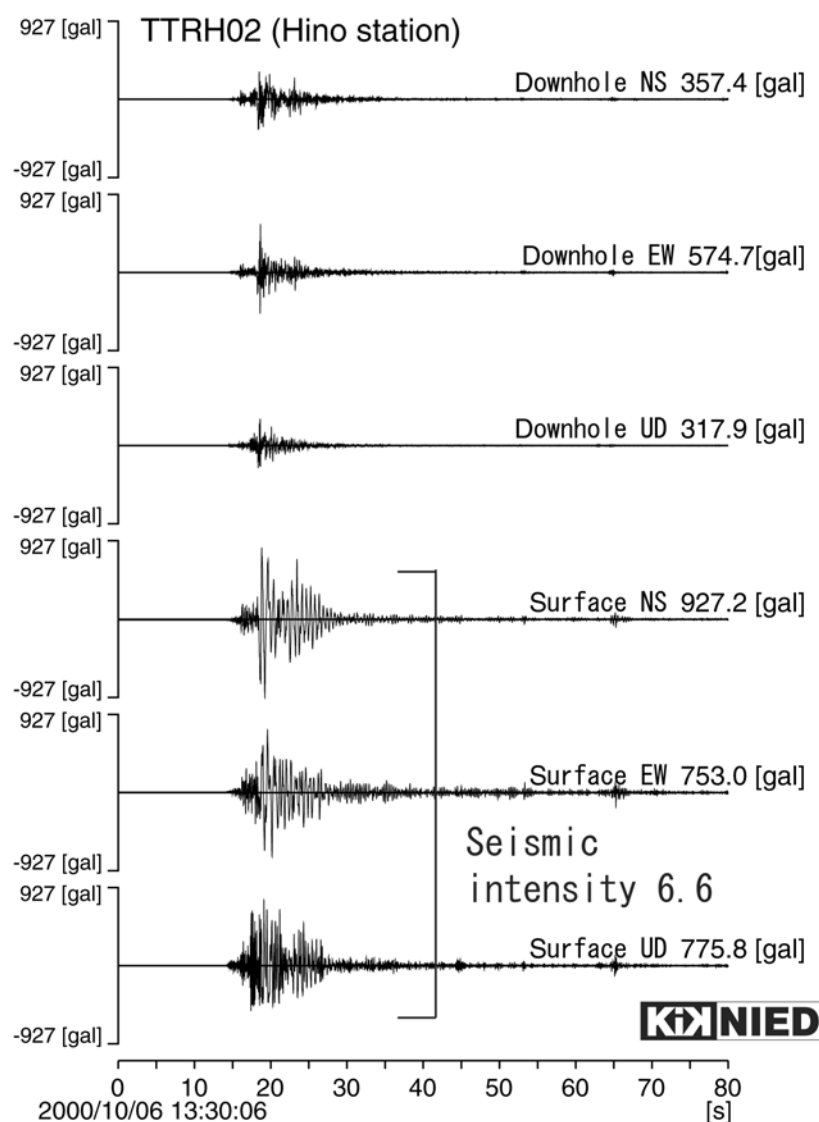


Fig. 5. Waveforms observed on the surface and the bottom of the 100 m deep borehole at Hino station (TTRH02) at 8 km away from epicenter. The maximum acceleration was 1135 gals (vector composition of three components) and the JMA seismic intensity was 6.6.

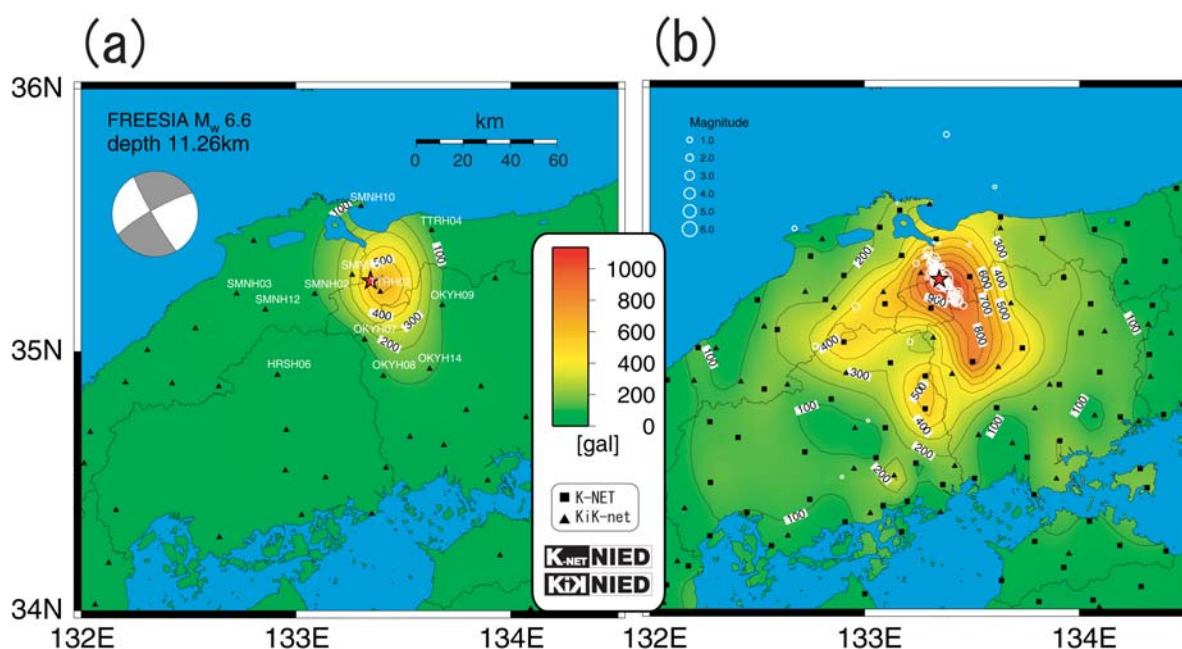


Fig. 6. The distribution of PGA associated with the 2000 Western Tottori earthquake (a) at 100-200 m depth and (b) on the ground surface. On (a), the moment tensor solution of F-net is shown. On (b), the aftershock distribution in the period, 13:30-23:59JST, October 6, is overlaid.

networks. One is the 2000 Western Tottori earthquake of 13:30 (JST), October 6, 2000 (Mw 6.6), that was the first inland earthquake of the over-M6.5-class after K-NET and KiK-net were deployed all over Japan. The other earthquake is the 2003 Tokachi-oki earthquake (Mw 8.0), which occurred in the southern Kuril subduction zone on September 26, 2003, 4:50 (JST), that was the first M8-class interplate earthquake around Japan after the beginning of the modern digital strong motion seismograph network was established.

### The 2000 Western Tottori earthquake

The 2000 Western Tottori earthquake (2000/10/06, 13:30 JST, 35.275N, 133.348E, 11 km; JMA, Mw 6.6) triggered 303 K-NET stations and 220 KiK-net stations. The nearest station, TTRH02 (Hino; epicentral distance of 8km, Fig. 5) recorded peak vector accelerations (vector summation of three components) of 1135 gals on the ground surface and 653 gals at the bottom of the 100 m borehole. This was the first JMA seismic intensity VII waveform recorded by our network. The waveforms were recorded at 31 stations within 100 km from the epicenter and 10 of them were within 50km.

Figure 6 shows the distribution of the peak vector accelerations around the source region, where (a) is the one at the bottom of the boreholes (100-200 m depth) of KiK-net, and (b) is the one on the ground surface of K-NET and KiK-net. Aftershock distribution in the period, 13:30-23:59JST, October 6, is overlaid in Figure 6(b). Compared to the simple elliptic pattern at the well bottom, the pattern on the surface is rather complex reflecting the variety of soil conditions. The similar tendencies in the distribution differences of peak accelerations were also observed for many earthquakes. The difference of the PGA distributions between downhole and surface records enables us quantitative evaluation of the site effects.

### The 2003 Tokachi-oki earthquake

The 2003 Tokachi-oki earthquake, occurred in the southern Kuril subduction zone on the 26<sup>th</sup> of September 2003, 4:50 JST (41.7797.N, 144.0795.E, 42 km; JMA, Mw 8.0). This earthquake was

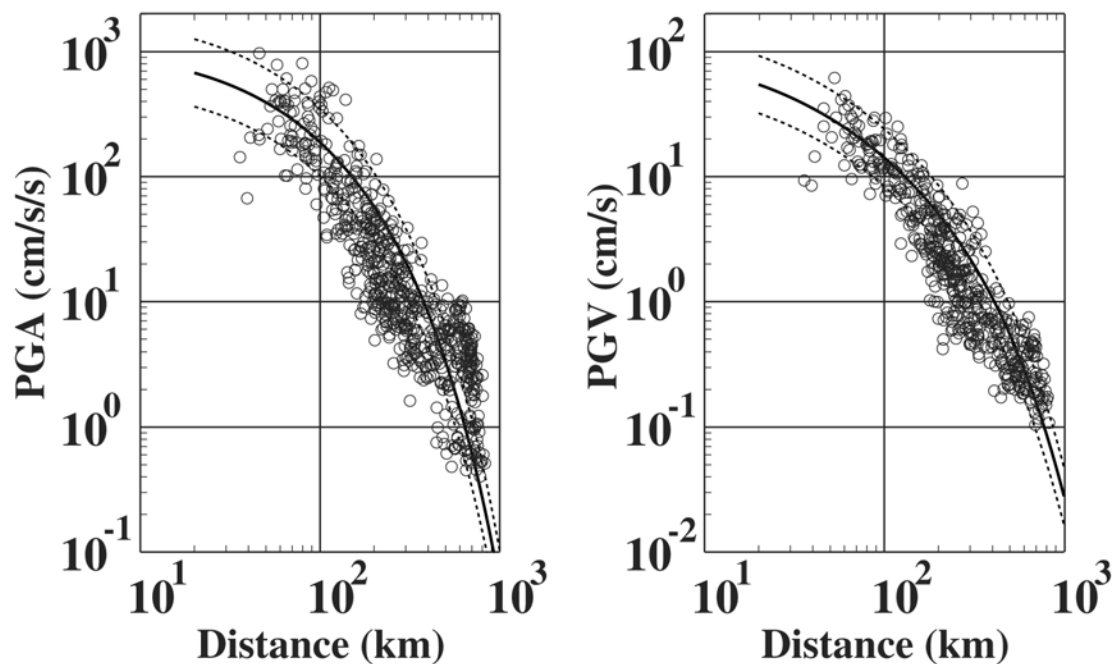


Fig. 7. Comparison between observed peak ground motions and an empirical attenuation relationship (dashed lines). Left: PGA at the surface. Right: PGV on the engineering bedrock ( $V_s = 600$  m/s), with the correction following by Si and Midorikawa (1999). Dotted lines indicate the standard deviations for the empirical relationships.

the first M8-class interplate earthquake around Japan after the dense and modern strong motion seismograph network was established. The ground motions due to the event were observed over a wide region covering 655 K-NET and KiK-net stations. The overall features of observed PGA (peak ground acceleration) and PGV (peak ground velocity) can be explained by empirical attenuation relationships (Fig. 7). A maximum PGA of 988 gals was observed at station HKD100 and amplitudes greater than 200 gals were observed over a wide area covering eastern Hokkaido.

Large oil tanks at Tomakomai, 200 km eastern away from the epicenter, located in the Yufutsu plane were seriously damaged by sloshing caused by the long duration of long period waves. The main cause of this phenomenon was the large plane structure with very thick sediment. The PGV distribution (Fig. 8) shows that the PGV at the Yufutsu plane was larger than its surroundings. Last year, NIED started to routinely analyze the source process for large earthquakes (Fig. 8) by waveform inversion under the vision that accumulation of rupture models is very useful in understanding the fault mechanism and also in evaluating the strong motion.

## DISCUSSION AND CONCLUSIONS

It is important in disaster mitigation to obtain various types of large-amplitude records and investigate the relationships between ground motion and damage. The 1995 Hyogoken-Nanbu earthquake made us realize again that there is a possibility that large earthquakes can occur anywhere in Japan, due to the great number of active faults all over the country and plates surrounding the Japanese Islands. To record these unpredictable strong motions as accurately as possible, NIED has constructed the permanent dense strong motion network, K-NET and KiK-net. Eight years have passed since K-NET went into operation, and during this time, it has provided large quantities of strong motion data including near fault ground motion of inland earthquakes such as the 2000 Western Tottori earthquake, and large interplate earthquakes such as the 2003 Tokachi-oki earthquake. Table 3 shows the records



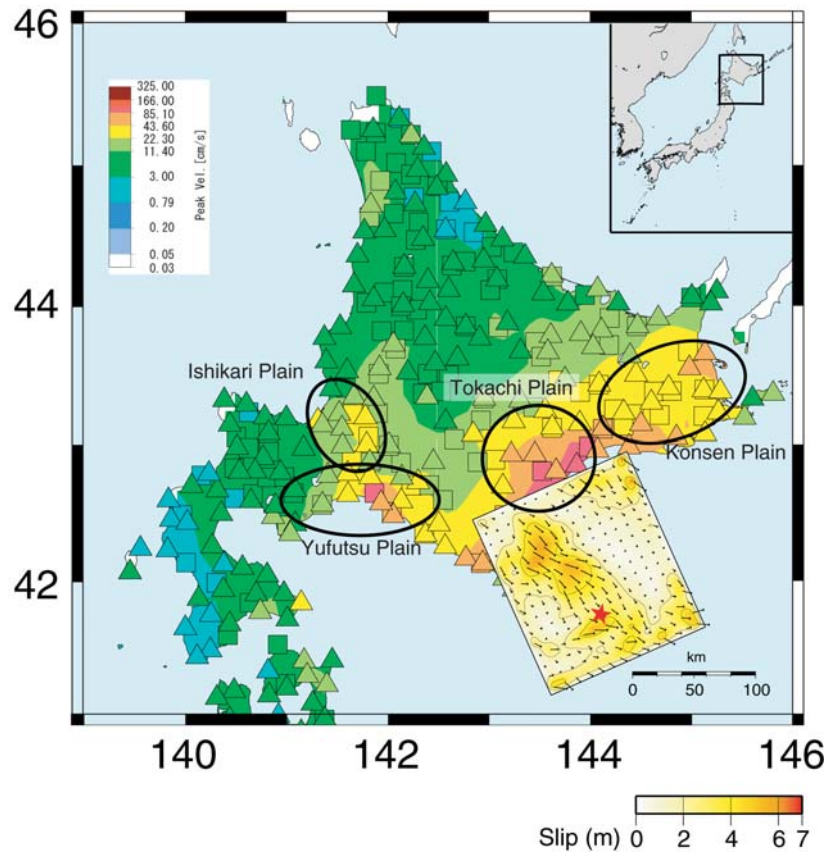


Fig. 8. Distribution of PGV and estimated total slip distribution by NIED. PGV's were obtained by integrating observed accelerations by K-NET and KiK-net. Star indicates the hypocenter. Slip distribution was estimated by a multi-time window analysis using K-NET and KiK-net data for a bandwidth of 5-50 seconds. (Honda et al., 2004).

that exceeded 900 gals. The dense network showed that the large accelerations were not accidental phenomena and PGA of over 1g (980 gal) is not a very rare occurrence, although they were observed within a spatially limited area. When observations are sparse, it is difficult to judge whether large ground motions are caused just by local conditions such as topography effects or soft soil like bank or not. We believe that it is necessary to maintain the network to record important strong motion data for expected future large earthquake.

Recently, the instruments at 443 K-NET stations, which indicated by blue circles in Fig. 1(a) have been replaced with a new system, the K-NET02. This new system has several advantages over the current system, the K-NET95. (1) K-NET02 has been officially approved as a seismic intensity meter by the JMA. Seismic intensity is automatically sent to JMA and DMC at NIED within two minutes after being triggered. This information will contribute directly to the decision and actions of administration. (2) K-NET02 will automatically call the DMC at NIED several seconds after being triggered and transmit waveform data even while recording. This function not only reduces much of the time for data collection but also helps in avoiding any overcrowding of telephone lines. The only practical countermeasure for overcrowding is to connect to the line before it becomes crowded. (3) The signal to noise ratio of K-NET02 in the long-period band has been improved by a factor of ten compare with the K-NET95. This will improve the accuracy of data analysis in the long period band such as waveform inversion analysis of source processes. NIED is now planning to replace the rest of the K-NET system in the near future because we believe that the new system will better contribute to both disaster mitigation and the acquisition of fundamental data in the field of strong motion seismology.

Table 3. Over 900 gals ground motions recorded by K-NET and KiK-net.

Site code	Site name	NS (gal)	EW (gal)	UD (gal)	Vector(gal)	Origin time	Latitude	Longitude	Dept (km)	Mj
KGS002	Izumi	727.3	541.8	246	903.1	NW. Kagoshima Eq. 1997/3/26 17:31	31.983	130.367	8	6.3
KGS005	Miyakonojyo	902.1	901	287.6	976.8	NW. Kagoshima Eq. 1997/5/13 14:38	31.95	130.3	8	6.2
TTRH02	Hino	927.2 -357.4	753 -574.7	775.8 -317.9	1142.4 -653.6	W. Tottori Eq. 2000/10/6 13:30	35.275	133.348	11	7.3
MYG011	Oshika	1103.5	1111.6	825	1571.3	Off-Miyagi Eq. 2003/5/26 18:24	38.805	141.682	71	7
MYG002	Utatsu	592.6	858.1	339.2	948.7					
IWT007	Kamaishi	593.8	1038.5	592.3	1055.9					
IWTH27	Rikuzen-takada	888.1 -167.1	556.1 -107.1	636.5 -85.6	1098.2 -167.2					
IWTH04	Sumita	729.6 -150.9	723 -105.7	1279.9 -114.2	1304.6 -175.3					
HKD100	Hiroo	810	972.6	461.2	988.4	Off-Tokachi Eq. 2003/9/26 4:50	41.778	144.078	42	8

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