RECENT PROGRESS OF SEISMIC OBSERVATION NETWORKS IN NIED

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ABSTRACT

After the disastrous 1995 Kobe earthquake, a new national plan called 'KIBAN project' has started to drastically improve seismic observation system in Japan. To construct dense and uniform networks covering whole Japan, it was designed to set up 1000 stations with average spacing of 20km for high sensitivity and strong motion seismographs, and 100 stations with average spacing of 100km for broadband seismograph. The construction of these networks were charged to the National Research Center for Earth Science and Disaster Prevention (NIED).

A large number of seismographs were newly installed to realize this plan. The new high-sensitivity seismograph network consisting of 696 stations are called Hi-net (High sensitivity seismograph network), which makes 1250 high sensitivity stations available if we include pre-existing stations. The new broadband seismograph network consisting of 71 stations is called F-net (Full-range seismograph network), which makes 100 broadband stations available if we include pre-existing stations. At most of Hi-net stations strong-motion seismographs are also equipped both at downhole and on the ground surface. The network of these 659 stations with a pair of strong-motion seismographs is called KiK-net (KIBAN Kyoshin network), while another network consisting of 1034 strong-motion seismographs settled at the ground surface is called K-NET (Kyoshin network). Here, Kyoshin is a Japanese word to mean strong-motion and all the station numbers above are as of April 2003.

High-sensitivity data from Hi-net and pre-existing seismic networks operated by various institutions have been transmitted to and processed by the Japan Meteorological Agency since October 1997 to monitor the seismic activities in and around Japan. The same data are distributed to university group in real time by using satellite communication for their research works. The data are also collected by NIED and stored in their database system for public use under fully open policy.

1. INTRODUCTION

Following the occurrence of disastrous Hyogoken-nanbu (Kobe) earthquake of January 17, 1995, Japanese government established the

'Headquarter for Earthquake Research Promotion' on July 18, 1995 and set up the 'Fundamental Survey and Observation Plan for Earthquake Research' on August 29, 1997. In short, this plan is called as the KIBAN project, where KIBAN is a Japanese word to mean fundamental or infrastructure.

The goals of this plan is to evaluate long-term possibility of earthquake occurrence through understanding of the earthquake phenomena and to make up a nation-wide probable shaking map through understanding of the generation mechanism of strong motions. In the concrete, the following items were selected as the core projects to be promoted with the highest priorities.

(1) Seismic observation
  a) High-sensitivity seismic observation (microearthquake observation)
  b) Broadband seismic observation
(2) Observation of strong motion
(3) Observation of crustal movement (continuous GPS observation)
(4) Survey of active faults inland and coastal regions

In this paper, we report the state of the arts regarding to the above items, (1) and (2). The KIBAN project recommended to construct seismic observation networks covering whole Japan at intervals of about 20km (100km for broadband observation) utilizing the existing stations as much as possible. It means approximately 1000 stations are needed for high-sensitivity and strong-motion networks and 100 stations for broadband network. The KIBAN project also requires that these observations should be stably and continuously maintained for at least several tens of years and the obtained data must be widely and quickly distributed to the public under fully open policy.

2. HIGH SENSITIVITY SEISMOGRAPH NETWORKS

When the Headquarter for Earthquake Research Promotion set up the KIBAN project, the policy to construct high sensitivity seismograph network was as follows. The magnitude of earthquake is determined from the fault size and the dislocation amount. If the deeper limit of the inland seismicity will be precisely clarified at a specified area, we can empirically estimate the maximum size of earthquakes at the area using scaling law. Since the depth limit of the seismogenic zone of inland earthquakes is usually 15-20km, it was requested to construct a seismic network with a spacing of 15-20km to assure precise focal depth determination of the earthquakes at such a depth. The KIBAN project recommended to construct an uniform network of high sensitivity seismographs covering whole Japan utilizing as much as possible pre-existing high sensitivity seismic stations of Japan Meteorological Agency (JMA), Universities (UNIV), and NIED. It also recommended to settle the seismograph in a borehole to avoid surface ground noise, to obtain physical properties such as P- and S-wave velocities along the borehole, and to co-locate a strong motion seismograph to supplement the scale out of the high sensitivity seismograph.

Based on the experience to construct the Kanto-Tokai network (Hamada et al., 1985), NIED was charged with the construction of the new seismic network, Hi-net (High sensitivity seismograph network Japan).

Under the condition that Hi-net must be operated by the staffs of limited number, data transmission and processing systems were designed to guarantee rational operation, easy maintenance, high reliability, and quick recovery from troubles, by adopting widely used modern technology and by extensive utilization of outsourcing services in system operation, maintenance and watching.

2.1 Hi-net station

To realize stable high sensitivity seismic observation avoiding surface ground noise, seismographs are settled at the bottom of the borehole of 100m depth or more at each Hi-net station (Figure 1). Short period three component velocity seismometers (1Hz, 200V/m/s) are installed at the bottom of the observation well together with three component accelerometers and two component borehole tiltmeters. A pressure vessel of 2.7m length containing these instruments is mechanically fixed in the borehole to assure possible pull up for repair or version up of the sensors in future.

As of April 2003, the number of Hi-net stations amounts to 696 (Figure 2) and the total number of high sensitivity seismic stations in Japan including existing ones reached to nearly 1250. Although majority of the Hi-net stations have the boreholes of 100-200m in depth, more deep observation wells were excavated at some specific sites if necessary.

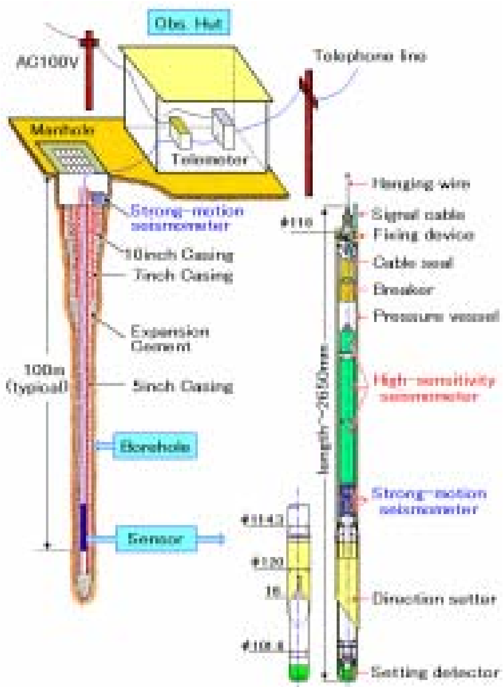

Fig. 1: Hi-net / KiK-net station

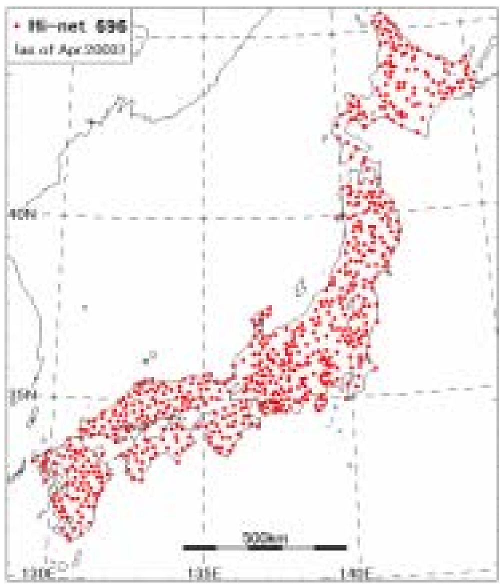

Fig. 2: Ditribution of Hi-net stations

2.2 Acquisition and transmission of Hi-net data

Seismic data at each Hi-net station are digitized with 24-bit A/D converters which are settled in a pit within the observation hut to avoid the effects of temperature change. The original data with a sampling frequency of 1kHz is decimated to 100Hz 27bit data, and is compressed to shape up a packet data of 1 second length being added a GPS time stamp (Figure 3).

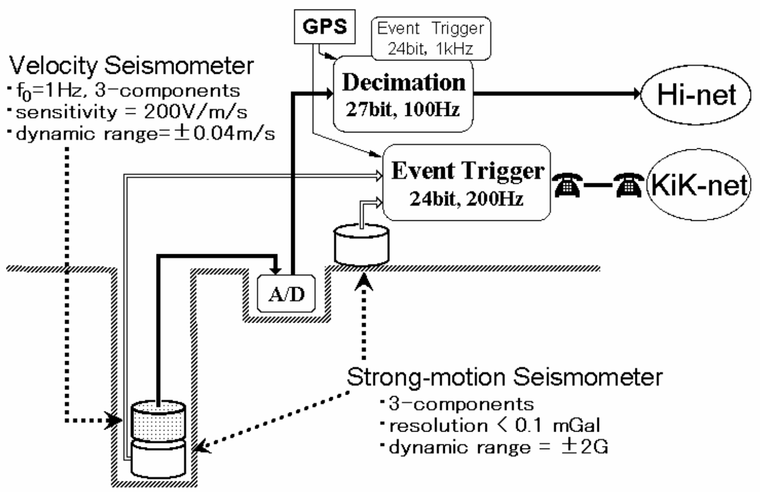

Fig. 3: Sensor and data acquisition at Hi-net/KiK-net station

Data acquisition system of the Hi-net forms a computer network as a whole. Each station is connected to the Hi-net Data Center in NIED by a frame relay (FR) network and TCP/IP protocol can be used for data transmission and network management. When the FR service is not available, the data are transmitted through a conventional analog telephone line to a relay point which is connected to the FR network. All the stations are divided like a checkered pattern and are connected to either of the Sub-center A (Tokyo) or B (Kyoto) so as to prevent simultaneous data loss in wide area in case of trouble at one of the Sub-centers A and B, although the Sub-centers are build in a communication network and are designed to be quite robust to such a trouble (Figure 4). Using this network, we can easily control each station of the Hi-net and can monitor the status of all the equipments connected to the network.

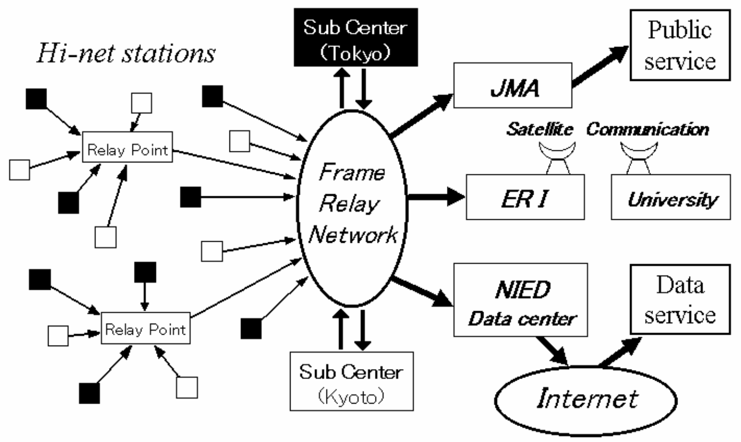

Fig. 4: Transmission of Hi-net data

Not only the Hi-net data, the seismic signals obtained at pre-existing seismic stations of JMA, UNIV and NIED are also transmitted to the Sub-centers and the whole data set are provided to the following three institutions. JMA receives the data to watch the seismic activity in 24 hour basis for public service to issue quick earthquake information. Earthquake Research Institute, University of Tokyo receives the data to redistribute real time waveform data to the researchers in local universities through a satellite communication link. NIED collects the whole data for archive and data service through internet.

At NIED, the data acquisition, monitoring, processing, and archive are controlled by a database management system. It automatically carries out a series of data processing such as event detection using STA/LTA, phase picking using AIC, determination of hypocenter and focal mechanism, spectral analyses, and extraction of waveform parameters. These event information and triggered waveforms are stored in a disk system at the Hi-net Data Center together with continuous records of all the components.

Under the concept that earthquake related information collected by the government are the common properties of the people, all the data obtained from the Hi-net are provided to the researchers and general public through internet under fully open policy. Users can retrieve raw data of the continuous or triggered waveforms of arbitrary stations. They can also browse the results of automatic hypocenter determination, the map of hypocenter distribution, the image of continuous record (1 hour length or 24 hour preview within recent 2 weeks) at arbitrarily selected station, and so on.

High quality data produced by the dense Hi-net are not only used for monitoring of seismic activity but are providing a plenty of seeds for interesting researches. For example, Obara(2002) found a phenomenon of non-volcanic deep tremor associated with subduction of the Philippine Sea plate over a length of 600km in southwest Japan.

3. BROADBAND SEISMOGRAPH NETWORKS

When the Headquarter for Earthquake Research Promotion set up the KIBAN project, it was requested to construct a broadband seismograph network with a spacing of 100km covering whole Japan utilizing existing broadband stations and the vaults as much as possible. The KIBAN project also recommended to co-locate a strong motion seismograph to supplement the scale out of the broadband seismograph.

Based on the experience to construct the FREESIA network (Fukuyama et al., 1996), NIED was charged with the construction of the new seismic network, F-net (Full-range seismograph network Japan).

3.1 F-net station

To realize stable broadband seismic observation avoiding temperature change, seismographs are settled at the depths of a vault of 30-50m long at each F-net station (Figure 5). As a broadband sensor, STS-1 (Wielandt and Streckeisen, 1982) was adopted at initial 22 stations. Later, since the manufacturing of the STS-1 was stopped, STS-2 seismometer was settled at the remaining stations. In the vault, three component velocity type strong

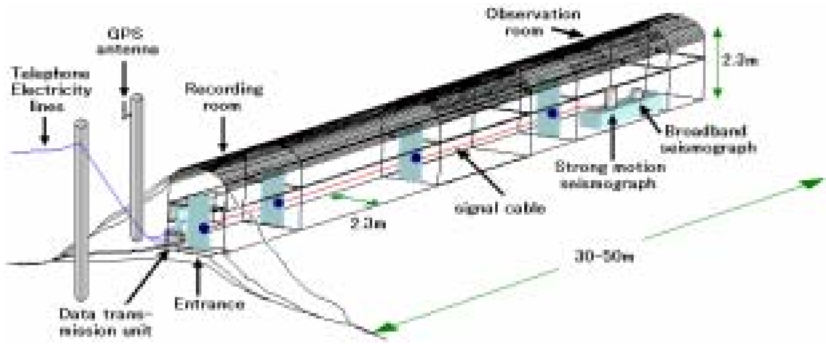

Fig. 5: F-net station

motion seismograph is also installed to extend the dynamic range of the observation.

As of April 2003, the number of F-net stations covering whole Japan reached to 71 (Figure 6) and the total number of broadband seismic stations in Japan including existing ones reached to nearly 100.

3.2 Acquisition and transmission of F-net data

In the beginning, a data logger, Q680 of Quanterra company is equipped st the F-net stations and the seismic data are digitized with 24-bit A/D converters with a sampling frequency of 80Hz and a GPS time stamp is added. These data are directly transmitted to NIED with a 64Kbps exclusive line using TCP/IP protocol.

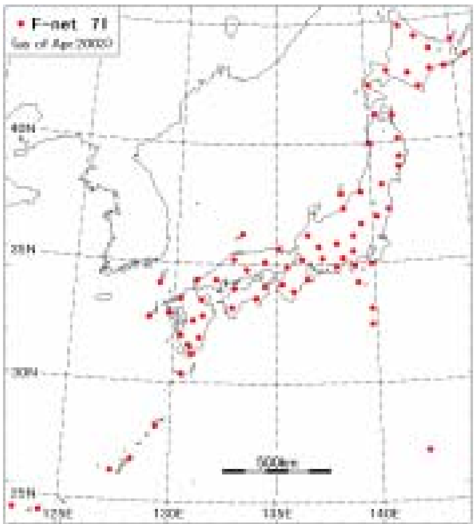

Fig. 6: Distribution of F-net stations

Later, to assure rational and efficient operation, the old system has been replaced with the Hi-net convertible ones. Now, all the stations are sharing the same data acquisition and transmission system as Hi-net using 27bit, 100Hz format.

At NIED, the continuous waveform records of all the F-net stations are stored in a disk system at the Data Center and are provided to the researchers and general public through internet under fully open policy. Users can retrieve raw data of the continuous waveforms of arbitrary stations. They can also browse the results of automatic CMT determination, the map of CMT distribution, the image of continuous record (1 day or 1 hour length) of arbitrary component at arbitrarily selected station.

High quality data produced by the F-net are providing some interesting research results. For example, Kumagai et al.(2001) developed a caldera formation model associated to the volcanic activity of Miyake Island in 2000, using very long period seismic signals observed by the F-net.

4. STRONG-MOTION SEISMOGRAPH NETWORKS

Just after the 1995 Kobe earthquake, NIED decided to make up a nation-wide network of strong motion seismograph, K-NET (Kyoshin network Japan), as an original project of NIED. It was planned to set up 1000 stations covering whole Japan with a spacing of 25km and to provide obtained data at once with a completely open policy.

Later, when the Headquarter for Earthquake Research Promotion set up the KIBAN project, it was recommended that strong motion seismograph will be co-located with high sensitivity seismograph when Hi-net station will be constructed. NIED installed an acceleration type strong motion seismograph at the bottom of the borehole together with a high sensitivity seismograph at newly constructed Hi-net stations. At that time, it was also planned to settle a strong motion seismograph of the same type on the ground surface just above the downhole instrument, thus forming a network of a pair of stong-motion seismographs, KiK-net (KIBAN Kyoshin network Japan).

4.1 K-NET station

At each K-NET station, an observation system called as K-NET95 is installed at the ground surface (Figure 7; Kinoshita, 1998). K-NET95 consists of three component acceleration type strong motion seismograph and a data logger having a 24 bit A/D converter with a sampling frequency of 100Hz and a 8MB memory which can record waveforms of 2.5hours in total. Resolution of the acceleration is less than 0.1 mgal and the maximum measurable acceleration is 2000gals. Internal clock of the recording system is calibrated by GPS signal every hour in the accuracy of 5 msec.

As of April 2003, K-NET consists of 1034 stations covering whole Japan (Figure 8).

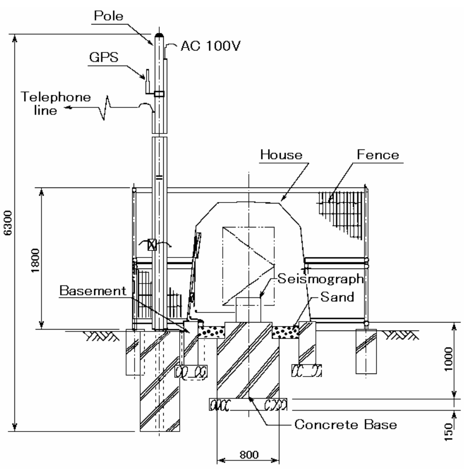

Fig. 7: K-NET station

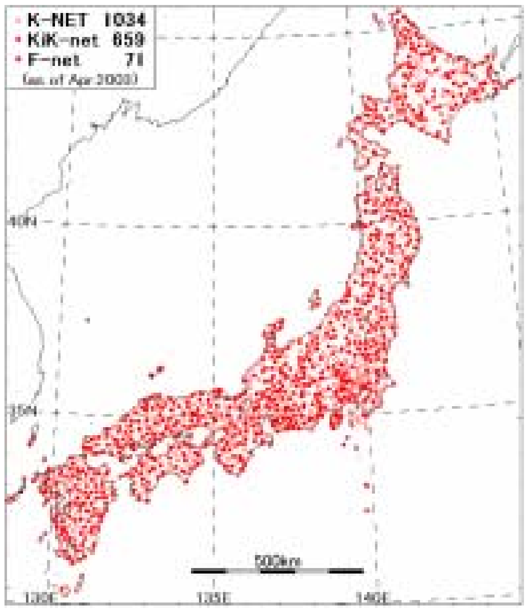

Fig. 8: Distribution of strong-motion seismographs

4.2 KiK-net station

At most of Hi-net stations, strong motion seismographs are installed both on the ground surface and at the bottom of the observation well (Figure 1) forming the KiK-net (Aoi et al., 2000ab). As of April 2003, KiK-net consists of 659 stations covering mainland Japan (Figure 8). While the K-NET stations were mainly constructed at the thick sedimentary sites in urban area, most of the KiK-net stations locate on the rock or thin sedimentary sites because the Hi-net is primarily designed for the purpose of highly sensitive seismic observation.

Instrumentation of the KiK-net is basically the same as that of K-NET95 used in the K-NET. The difference is a sampling frequency of 200Hz and 85MB memory which can hold 6 component waveforms of 6.5 hours in total. The event trigger system of the data recorder is controlled using the signal of the downhole seismometers. Typically, event recording is started with a threshold level of 0.2-0.4 gals and ended with 30 seconds continuation of the level below 0.1 gals, keeping minimum recording length of 120seconds.

4.3 Acquisition and transmission of K-NET and KiK-net data

Strong motion data of K-NET and KiK-net are collected through the dial up operations by the Data Center of NIED. When an earthquake which registered JMA intensity 3 or more JMA issues a quick report of source parameters through a JMA satellite. Upon receiving the quick report, the data center automatically estimate the distribution of maximum acceleration using an empirical attenuation relation (Fukushima and Tanaka, 1990) and starts to retrieve the strong-motion records of necessary stations using 25 telephone lines

Dial up operation often encounters troubles by jamming of communication traffics and the data collection considerably delays especially in case of large earthquakes. To resolve this problem, the renewal to a data acquisition system using dial out operation is currently in progress. The new system will first be introduced at 420 K-NET stations in western Japan in 2003.

At NIED, the collected waveform records of all the K-NET and KiK-net stations are stored in a disk system at the Data Center and all the data are provided to the researchers and general public through internet under fully open policy. Users can select specific events or stations with a combination of key parameters to download the raw data. They can also browse, select, and retrieve various information such as distribution map of acceleration, paste up of waveforms, station map, site information including soil condition and logging data, and so on.

Six component records obtained from a paired strong motion seismographs at each KiK-net station enable us to quantitatively evaluate the site effect at the station. For example, associated to the occurrence of the western Tottori earthquake of October 6, 2000, the nearest station, HINH (Hino; epicentral distance 8km), recorded peak amplitudes of 927 gals in UD-component on the ground surface but it was 574 gals in EW-component at the bottom of 100m borehole. Figure 9 shows the distribution of peak accelerations around the source region, where (a) is the one at 100-200m depth, and (b) is the one on the ground surface. Epicentral distribution in the period, 13:30-23:59, October 6, is overplotted on (b). Compared to the simple elliptic pattern in (a), the pattern of (b) is rather complex reflecting the variety of soil conditions and amplification factors at each site.

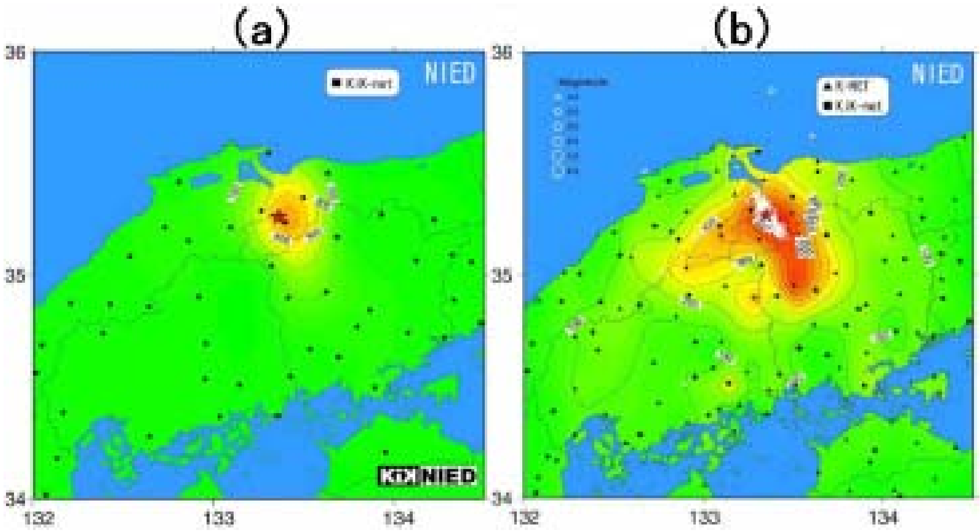

Fig. 9: Distribution of peak accelerations at (a)100-200m depth and (b) on the ground surface associated to the western Tottori earthquake (M7.3) of October 6, 2000.

5. SUMMARY

Following the KIBAN project by the Headquarter for Earthquake Research Promotion, NIED made up several kinds of extensive modern seismic networks covering whole Japan, Hi-net, F-net, K-NET, and KiK-net. The total number of the stations operated by NIED amounts to nearly 2000.

All the high-sensitivity data including Hi-net and pre-existing seismic networks operated by various institutions are transmitted to and processed by JMA to monitor seismic activity in and around Japan. At the same time, the data are distributed to university group for a variety of research works and to NIED for data archive and distribution under fully open policy. All the data obtained by these networks are now open to any use through world-wide web (http://www.bosai.go. jp/) .

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