Recent Progress of Seismic Observation Networks in Japan

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Abstract. Before the occurrence of disastrous Kobe earthquake in 1995, the number of high sensitivity seismograph stations operated in Japan was nearly 550 and was concentrated in the Kanto and Tokai districts, central Japan. In the wake of the Kobe earthquake, Japanese government has newly established the Headquarters for Earthquake Research Promotion and started the reconstruction of seismic networks to evenly cover the whole Japan. The basic network is composed of three seismographs, i.e. high sensitivity seismograph (Hi-net), broadband seismograph (F-net), and strong motion seismograph (K-NET). A large majority of Hi-net stations are also equipped with a pair of strong motion sensors at the bottom of borehole and the ground surface (KiK-net). A plenty of high quality data obtained from these networks are circulated at once and is producing several new seismological findings as well as providing the basis for the Earthquake Early Warning system. In March 11, 2011, “Off the Pacific coast of Tohoku Earthquake” was generated with magnitude 9.0, which records the largest in the history of seismic observation in Japan. The greatest disaster on record was brought by huge tsunami with nearly 20 thousand killed or missing people. We are again noticed that seismic observation system is quite poor in the oceanic region compared to the richness of it in the inland region. In 2012, NIED has started the construction of ocean bottom seismic and tsunami observation network along the Japan Trench. It is planned to layout 154 stations with an average spacing of 30km, each of which is equipped with an accelerometer for seismic observation and a water pressure gauge for tsunami observation. We are expecting that more rapid and accurate warning of earthquake and tsunami becomes possible by this observing network.

1 The following slides are from the presentation given by Dr Yoshimitsu Okada at the Irago Conference 2012. Each slide is accompanied with an explanatory notes.
Recent progress of seismic observation networks in Japan
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Figure 1. Recent progress of seismic observation networks in Japan.

Figure 2. This figure shows the world distribution of earthquakes of magnitude 4 or greater and focal depth shallower than 100km, which were generated within recent 10 years (1985-1994). Seismic belts correspond to plate boundaries and we can hardly recognize the shape of Japanese islands.
Figure 3. As can be seen in the seafloor topography, tectonic setting around Japanese islands is very complex. Beneath the Japan, the Pacific plate is subducting from east to west and another Philippine Sea plate is subducting from south-east to north-west. Japanese islands itself is considered to belong to the Eurasian plate in its southwestern part, while it belongs to the North American plate in its northeastern part. Such a complex tectonic situation is producing a large number of earthquakes and volcanoes in Japan.

Figure 4. Along the Japanese islands, it is known the aligned regions of M8-class inter-plate earthquakes. Among them, the Tokai and Kanto earthquakes are rather special in the sense that their focal area is landing inside of the Japanese islands. The Kanto area has a dense population of 40 million and is bearing an economical and political center of Japan, while the Tokai area has another population of 10 million and is bearing a main channel of traffics connecting eastern and western Japan.
Figure 5. This figure shows the seismograph network in Japan before the 1995 Kobe earthquake was happened. By the circumstance as already stated in the previous slide, a lot of seismic stations were concentrated in the Kanto and Tokai districts.

Figure 6. Here, let me explain the principle of seismograph. It is simply using the law of inertia. If we move hand very quickly, the hanged pendulum does not move and hold its original position. So, when we construct such a system with pendulum and rolling paper, we can get a trace of ground vibration if the ground moves quickly.
Ground noise
Seismic wave
A sample of seismic record
High sensitivity seismic observation
To avoid ground noises, sensor is set at the bottom of borehole

Figure 7. If we set a seismograph on the ground, we will soon get such a seismic record. This is composed of a seismic wave and ambient ground noise. When we want to detect very small earthquake signals, the ground noise becomes main obstacle for the observation. So, for a high sensitivity seismic observation, we usually set the sensor at the bottom of a borehole to avoid the ground noises. The depth of the borehole is usually around 100-200m.

Deep Borehole Observatories around Tokyo

Figure 8. However in the metropolitan region such as Tokyo, the ground noise is so high that the borehole depth of 100m or so is not enough to achieve high sensitive seismic observation. In such a case, we need very deep borehole of around 3,000m depth penetrating a soft sedimentary layer and reach to the hard basement rock. The left picture shows the outlook of the Fuchu Deep Borehole Observatory in western Tokyo.
**Figure 9.** The effect of the Deep Borehole Observatory is enormous. This figure is comparing the seismic records of a micro-earthquake of M2 obtained at a shallow borehole station and a deep borehole station. We can clearly identify P- and S-phases using the deep borehole record. Using such high quality data, we can now catch a precise image of hypocenter distribution under Tokyo Metropolis. The right figure compares the east-west cross section beneath Tokyo down to 200km. The top is an image obtained by a conventional seismic network and the bottom is the one including the data from Deep Borehole Observatories. Although the seismic zone corresponding to the subduction of the Pacific plate can be seen in the both images, the shallow seismic activity corresponding to the subduction of the Philippine Sea plate can be recognized only in the bottom image.

**Figure 10.** Using such a dense observation network, seismic activities around Kanto and Tokai...
(continued) districts were investigated in details. The left figure shows the hypocenter distribution in the Tokai region and we can identify a locked zone in the cross sectional view along the subduction of the Philippine Sea plate. This locked zone is believed to generate hypothetical Tokai earthquake in future. On the other hand, the right figure shows a three-dimensional hypocenter distribution beneath the Tokyo Metropolis showing complex structure of the overlaid Philippine Sea plate and the Pacific plate.

**Figure 11.** The Kobe earthquake of 1995 gave a great impact to the system of earthquake research in Japan. The trend of prediction-oriented study was changed to direct more basic researches, and the Headquarters for Earthquake Research Promotion was newly established in the Government.
The goals of this Headquarters were to evaluate the long-term earthquake occurrence and to make up a probable shake-map covering the whole of Japan through basic research of earthquakes. To achieve this goal, the KIBAN project was started. KIBAN is a Japanese word to mean fundamental or infrastructure. It was composed of three components, construction of a nation-wide seismic network, construction of a nation-wide GPS network, and systematic active fault survey covering the whole of Japan. Hereafter, we refer only to the seismic network.

Since the ground motion has wide spectrum both in amplitude, and shaking period, we need three kind seismographs to cover all the ground motions, i.e. strong motion seismograph, broadband seismograph and high-sensitivity seismograph.
Figure 14. At first, broadband seismograph is settled in a backroom of an observation vault to avoid various meteorological disturbances.

Figure 15. Before the Kobe earthquake, the distribution of broadband seismograph was very sparse and inhomogeneous, and almost all stations were not operated in real-time mode. In the KIBAN project, nearly 70 broadband seismograph stations were added with an average spacing of 100km and started operation in on-line real-time mode. This network is called F-net (F means full-range).
Figure 16. Next is the strong motion. After the Kobe earthquake, NIED has constructed a strong motion network called K-NET (K is an initial of Kyoshin which means strong motion in Japanese). At a K-NET station, three-component accelerometer is settled on the ground surface and the triggered records are transmitting via telephone line. With an average spacing of 20km, about 1,000 stations were constructed covering the whole of Japan.

Figure 17. Before the Kobe earthquake, a nation-wide strong motion network was operated by JMA with nearly 250 stations. Since the density is insufficient to delineate precise shaking distribution, 1,000 K-NET stations were added after the Kobe earthquake. Moreover, through the KIBAN project, strong motion seismographs were also equipped in parallel at the F-net and Hi-net stations.
High sensitivity seismograph (Hi-net)

**Figure 18.** The last is the high sensitivity observation. To assure high sensitivity, sensors are installed at the bottom of borehole to avoid the near surface ground noises. Although the depth of borehole is usually 100-200m, more deep borehole reaching to 2,000-3,000m are used if necessary. This network is called Hi-net (Hi is the initial of High-sensitivity).

**Figure 19.** Now, about 800 Hi-net stations are in operation covering the whole of Japan with an average spacing of 25km. At the majority of the Hi-net stations, a strong motion seismograph is installed both at the ground surface and at the bottom of borehole. This network of a paired strong motion seismograph is called KiK-net (Kiban Kyoshin network).
Figure 20. Before the Kobe earthquake, high sensitivity seismograph networks in Japan were independently operated by JMA, universities, and NIED. JMA was operating a sparse but nationwide network, while universities and NIED were operating local networks covering the each area of concern.

Figure 21. Thus, nearly 550 high sensitivity seismic stations were operated in Japan before the Kobe earthquake. After the Kobe earthquake, all these data were tentatively concentrated to JMA and a unified data processing was started in October 1997. Still the distribution of high sensitivity seismic station was inhomogeneous and its density was not enough. To improve this situation, about 800 Hi-net stations were newly constructed.
Distribution of high sensitive seismic stations in west Japan before Kobe Eq. after Kobe Eq.

Figure 22. This figure shows how high sensitivity seismograph network was intensified in the western Japan.

Distribution of Hi-net and K-NET stations around here

Figure 23. This map shows the distribution of Hi-net and K-NET stations around here, the Irago Cape. Red points show the Hi-net stations, while yellow ones show the K-NET stations. Imagine the seismic network is covering the whole of Japan with such a high density.
Figure 24. The data from Hi-net is primarily used for hypocenter determination. On average, about 20,000 earthquakes are located every year. This figure shows the hypocenter distribution around Japanese islands, where red points show the shallow events while blue ones correspond to the deep events.

Figure 25. This figure shows an example of the results obtained from the KiK-net and K-NET. Associated to the occurrence of the western Tottori earthquake of October 2000, the distributions of the ground acceleration were obtained at both of the 100-200m depth level and the ground surface. Compared to the simple concentric pattern at depth, we can see a complex pattern at the surface reflecting the complexity of the ground conditions.
Figure 26. As the result of Hi-net observation, we could find the phenomena of deep tremor at southwest Japan for the first time in the world. They are generated along the depth contour of the Philippine Sea plate and correspond to the focal areas of the forthcoming mega-thrust earthquakes, Tokai, Tonankai, and Nankai. In a cross sectional view, the tremor is located at the deeper extension of the mega-thrust earthquake and is combined with slow slips of various time scale. We are expecting some new hints will be obtained as to the generation mechanism of big earthquakes.

Figure 27. As a whole, NIED is now operating about 2,000 seismic stations in the Japanese islands.
**Figure 28.** These seismic data are exchanged in real time among JMA, universities, and NIED. JMA is using them for monitoring and watching, while university groups are using them for the purpose of academic researches and education. NIED has a role of data archiving and sharing to provide them to the general public, officials, and private sector.

**Figure 29.** As a practical application of the dense seismic network, Hi-net data are utilized for realization of the Earthquake Early Warning System. In Japan, the service of Earthquake Early Warning to specific users was started in August 2005 and the service of them to general public was started in October 2007 for the first time in the world.
Figure 30. The principle of Earthquake Early Warning is as follows. When an earthquake occurs, it generates the elastic waves of two kind, P-wave and S-wave. P-wave is faster than S-wave but its amplitude is generally far small compared to that of S-wave. At this yellow point, P-wave is already arrived but S-wave is not yet arrived. If this information is transmitted to the remote place at once, they can prepare to the earthquake before the large shaking of S-wave comes or even before the arrival of the P-wave.

Figure 31. This is an example of scenario. When an earthquake happens here, first signal is detected at the nearest observation site. After some data processing and transmission, a quick Early Warning is issued within several seconds and the various controls are started to traffics, plant operation, and so on. At this Shizuoka City, a large shaking will arrive about 10 seconds later, and it will arrive at Tokyo 40 seconds later.
Figure 32. This picture shows a scene of the training at the Nagamachi Elementary School in Sendai City. Pupils are hiding under the desk receiving an Early Warning information that shaking of intensity 4 will come 12 seconds later.

Figure 33. Here, let us remind the great East Japan Earthquake of March 11 of the last year, which recorded M 9.0, the largest in the history of seismic observation in Japan. This picture shows the instance that tsunami arrived at the coast of Miyako City. As you can see, tsunami is not a big wave but the flood coming from the ocean.
Figure 34. This diagram shows the tsunami height distribution. Most severe tsunami were concentrated in the Sanriku region with 30 to 40m run-up heights. When this earthquake occurs, the first information issued from the JMA was remarkably underestimated. The magnitude of the earthquake was guessed as M 7.9 and the estimated tsunami height level was announced only 3 to 6 meters in the first Warning. One reason for such an underestimation was the lack of data in the ocean area. Compared to the dense networks in the land area, seismic and tsunami observation in the ocean area was crucially insufficient.

Figure 35. By the occurrence of the great East Japan earthquake, we are anxious about possible triggering of large inter-plate earthquakes in the surrounding region. In the case of 2004 Sumatra earthquake of M 9.1, a big thrust earthquake of M 8.4 was followed three months later at the neighboring area. We should be cautious to the similar phenomena for the East Japan earthquake,
especially at northern and southern extensions of the focal area of the main shock. In the northern extension, relatively large earthquakes were occasionally generated such as 1968 Tokachi and 1994 far off Sanriku earthquakes. On the contrary, in the southern extension we have only little records of the large earthquakes excluding 1677 off Boso earthquake of M8.0. It is said that this historical earthquake accompanied a big tsunami and gave considerable damages in the coastal areas of the East Japan.

![Ocean bottom cabled network along Japan trench](image)

**Figure 36.** In order to improve the observation capability in this region and to prepare to the next big one, our institute, NIED has started the construction of an ocean-bottom cabled network along the Japan trench. Colored dots in the ocean show the locations of pressure vessel in which a set of seismometers and pressure gauges for tsunami detection are included. The network is consisted of 154 stations in total with a spacing of about 30km in the East-West direction and in a spacing of 50-60km in the North-South direction with a total cable length of 5,800km. In the fiscal year of 2012, red colored Boso network and green colored Aomori network are scheduled to start the operation. We are hoping that this network will contribute to monitor large earthquakes and tsunamis which may attack east Japan and to successfully transfer more rapid and accurate warnings to the general public.
Thank you for your kind attention