COMMENT

SEISMOLOGY Lessons learned from the megaquakes of the past decade **p.149**

NUCLEAR ENERGY Economics should dictate how we respond to Fukushima **p.151**

PHOTOGRAPHY The woman who caught physics on film **p.156**

NEUROSCIENCE Pianist Vijay Iyer riffs about jazz and cognition **p.157**

MIYAKO CITY OFFICE/REUTERS

The 2011 Japan tsunami breached 10-metre-high walls in Iwate Prefecture, where warnings predicted a wave only 3 metres high.

Putting seismic research to most effective use

Today's tools and geophysical knowledge could be utilized more effectively for earthquake hazard mitigation, says **Hiroo Kanamori**.

A year has passed since a devastating tsunami inundated large areas of the northeastern coast of Japan, with tragic consequences. Given that it remains too difficult to make accurate short-term predictions of earthquakes, at least for now, the question is what we can do to improve earthquake damage mitigation.

The 2011 magnitude-9 Tohoku-Oki earthquake clearly demonstrated that seismologists can rapidly and quantitatively determine what has happened during a quake, thus reducing its impact and the number of lives lost. Yet there is much room for improvement. Real-time data are not being fully shared between nations, and the best monitoring tools have not been fully implemented. More should be done to encourage the practical use of seismic research. At present, there is too large a gap between academic work and the reality of hazard mitigation.

A YEAR AFTER THE TSUNAMI
For more content, go to:
www.nature.com/japanquake

Thanks to the extensive global seismic network established over the past three decades, the world's seismic activity is constantly monitored in real time by the National Earthquake Information Center (NEIC) of the US Geological Survey. Some 20 minutes to an hour after the onset of the Tohoku-Oki earthquake, the NEIC had located the epicentre and determined that the ▸

magnitude was about 9, with a faulting mechanism typical of subduction-zone great earthquakes[1]. This information was crucial for alerting the emergency services. Such a rapid determination was not possible until recently; in 2004, it took hours or days for similar warnings to be issued[1].

Even more rapid determinations, within just a few minutes of an earthquake, can make a great difference to local warnings. Within 3 minutes of the Tohoku-Oki quake, the Japan Meteorological Agency (JMA) system came up with an initial estimate of magnitude 7.9 for the quake. On this basis the agency issued a warning of 6-metre tsunamis along the coast of Miyagi Prefecture, and 3-metre tsunamis along the coast of neighbouring Iwate and Fukushima prefectures. Exactly how many lives were saved by this rapid warning is hard to determine; perhaps many thousands[2]. Unfortunately, some residents in Iwate Prefecture, where tsunami walls as high as 10 metres had been built, assumed that they would be safe from tsunamis less than 3 metres tall and did not take immediate action. In the end, the tsunami overtopped many of these walls.

ROOM FOR IMPROVEMENT

Forecasters could improve warnings simply by using existing technology better. Crucially, a rapid tsunami-warning system needs to have access to high-quality data at short distances, and a method that can determine both the magnitude of the earthquake and the mechanism of faulting. The latter requires the use of both short-period seismic wave information and, for large earthquakes, longer-period wave information. The JMA has high-quality data, but has not yet implemented the best methodology: its current system uses only short-period information, which led to the initial underestimate of the magnitude of the Tohoku-Oki quake. It has been testing a better system offline since 2008, but has not yet put it into action. The NEIC, by contrast, has a good methodology, but does not have sufficient access to real-time local data. Although Japan is covered with hundreds of broadband seismographs that are suitable for warning of tsunamis, the data from only a handful are made available to the NEIC in real time. The number of stations worldwide sending real-time data to the NEIC has gone up from 350 in 2004 to 1,183 in 2011 (ref. 1). Hopefully this trend will continue.

"Forecasters could improve warnings simply by using existing technology better."

Ideally, both the NEIC and JMA should improve their systems in those aspects in which they are lacking, so that we can have backup systems in place for verifying the impact of ongoing earthquakes. This is especially important when the operation centres in the affected country are incapacitated by a natural disaster.

In addition to seismic data, high-rate Global Positioning System (GPS) data that can reveal the scale of large ground motions are now available. Several research groups are developing new methods for using real-time GPS data in rapid warnings. These should enable an estimation of fault size in addition to earthquake magnitude, and could therefore produce better tsunami warnings. In Japan, for example, this methodology could produce accurate warnings within just a few minutes.

Real-time international exchange of both seismic and GPS data is therefore vital for more rapid, reliable and robust warnings.

Japan also has a nationwide earthquake early-warning system, which can give 1–30 seconds of warning (compared with a warning time of 5–30 minutes for a tsunami) by detecting the first signs of shaking. This was successfully deployed during the Tohoku-Oki earthquake, although the extremely complex rupture process, along with the many aftershocks, confused the system and forced it to be shut down temporarily.

The most effective application of this type of early warning is when it is paired with engineered systems that will automatically shut down in the event of strong shaking, as with the Japanese bullet trains. At the time of the Tohoku-Oki earthquake, about 24 trains were running in the affected area, some at speeds in excess of 200 kilometres an hour. Emergency braking started within a few seconds, bringing all the trains to a halt without a single derailment, significantly damaged train, serious injury or death. Similar automated systems are now in use by some private companies.

It is essential that seismologists work closely with engineers to optimize these and similar systems. The merit of many of the academic theories and methods produced by seismologists may not be obvious to industry, and there are few financial incentives to make them more practical. By contrast, in the materials and biomedical sciences, good products developed in academia are much more likely to be picked up by industry because they can be developed into profitable products. It is important for seismologists and geophysicists to take a more active role in promoting interaction and collaboration between disciplines and with industry.

It is equally important to cultivate good human resources. One lesson learned from the Tohoku-Oki earthquake is that nature occasionally acts in ways that contradict our assumptions (see page 149). It is important to train students of science to have flexible and creative minds that can challenge the conventional view (about where large earthquakes can happen, for example) before a disaster forces a rethink. As many scientific projects get bigger, young scientists tend to be overwhelmed by the highly technical issues. We need to encourage them to take a step back and to see the big picture, rather than becoming overly specialized at a young age or locked into conventional ways of thinking. ■

Hiroo Kanamori *is a seismologist at the California Institute of Technology in Pasadena, California 91125, USA.*
e-mail: hiroo@gps.caltech.edu

1. Hayes, G. P. *et al. Seismol. Res. Lett.* **82,** 481–493 (2011).
2. Heki, K. *Science* **332,** 1390–1391 (2011).

JI CHUNPENG/XINHUA/ZUMAPRESS.COM VIA NEWSCOM

The Japan Meteorological Agency issues tsunami warnings within minutes of an earthquake.