When catastrophes collide

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Very few buildings were able to withstand the destructive force of the tsunami on March 11 in Japan. Credit: Keystone

Japan's earthquake early warning system worked according to plan: the alarm was set off before the seismic waves reached Japan. The buildings were also able to withstand the tremors in many places, with most of the destruction caused by the tsunami. On the other hand, the nuclear crisis triggered as a result may be partly attributable to a failure to gauge accurately the intensity of possible quakes as well as risk analysis that was not comprehensive enough.

As expected, the earthquake on March 11 with a magnitude of 9 triggered a tsunami off the coast of Japan as a result of its intensity. The displacement of the oceanic crust off the coast near Sendai which was caused by the earthquake temporarily raised the sea level by 7.2 metres.

This figure was calculated by measuring stations located off the coast of Japan. However, experts say that estimates based on the height of the protective walls and how much water they could resist as well as the actual effects observed clearly indicate that in places the water level was significantly higher than the figure measured, and that a tsunami height of “more than ten metres” is probably a conservative estimate. In some places the sea travelled more than four kilometres inland. Only a few sturdily constructed buildings were able to hold out against the destructive force of the deluge.

About an hour after the quake, the emergency generators in the Fukushima nuclear power plant shut down, ultimately leading to an acute loss of cooling power and to a nuclear emergency that has still not been brought completely under control. It is not yet possible to gauge the consequences of this failure. It is very difficult to comprehend what has happened and is still happening in Japan, or indeed the stoicism with which the Japanese people are responding to the disaster. Current estimates of the number of fatalities caused by the natural disaster stand at roughly 20,000. In a worst case scenario, there will be further victims from the effects of nuclear radiation in the medium and long term.

Earthquakes as a trigger for the chain reaction

While the factors that gave rise to the nuclear emergency – namely the earthquake and the resulting tsunami – have now faded into the background in the media, there are still a lot of unanswered questions for the seismologists. They are now analyzing the earthquake and the multitude of seismic data that it produced. These analyses are indicating that the earthquake models for the Sendai region and presumably also for other regions along the Pacific coasts will have to be completely updated. Before the earthquake on March 11, official sources had never anticipated quakes of this magnitude in the region. The quake, which is now referred to as the Tohoku earthquake, is listed by the US Geological

Survey as the fourth-strongest on our planet since earthquakes were first recorded using modern equipment 130 years ago.

Japan is in a highly active tectonic zone where the Eurasian, Philippine Sea, Okhotsk and Pacific Plates converge. The unexpectedly strong quake took place where the Pacific Plate sinks under the Okhotsk Plate (subduction). In the affected region, the submerging Pacific Plate is very old and heavy and is sinking into the Earth's core at a relatively high speed of 8 to 10 centimetres per year. For this reason, some scientists assumed up to now that earthquakes with the intensity of the one that just hit Japan could only take place where the submerging plate is younger and, because of its physical properties, does not sink in under another plate that 'easily'. Up until now, no quakes stronger than 8.2 were expected for the Sendai region.

Earth thrown off balance

However, at a public lecture on the earthquake that was organized by the Swiss Seismological Service (SED), Domenico Giardini, the director of the SED, emphasized that in a region where ten metres of crust plate subduction takes place every hundred years, earthquakes with a magnitude of 9 are inevitable. "The earthquake filled a gap", he said, where built-up energy was released. But, he said, it was also clear that the Japanese model used to date for the Sendai region concerned was not correct. In the past, he explained, it was assumed that the faults were different, consecutive and "discrete". Each of them was considered separately and also classified separately in terms of the expected intensity of earthquakes. But the earthquake now has taken place along the entire line of segments: over a period of 150 seconds, the oceanic crust off the coast of Sendai ruptured over a length of approximately 300 kilometres from the tectonic tension. The strong tremors lasted for around the same unusually long period. According to Giardini, these tremors normally last for roughly 5 to 20 seconds. Because the focus of

the earthquake was very large, however, strong shakes were registered in Japan for a period of 120 seconds. Giardini explained: “The Japanese province of Honshu moved 5 metres east and the Pacific Plate moved 10 metres west.” As a result of the huge displacements of mass, the Earth shifted 10 centimetres on its axis. Giardini predicted that strong aftershocks can be expected for months to come, which could reach a magnitude of 8 or more.

New faults activated

However, Professor Giardini does not expect these aftershocks to cause major problems. He is more concerned about the fact that the quake has activated at least ten more faults in the Japan region, some of which are quite dangerous. Giardini also pointed out that the tectonic situation around Japan has been puzzling seismologists for a long time now. For example, almost all of the major earthquakes in Japan over the past ten years took place in locations where they were least expected. By contrast, there was no movement in locations where heavy earthquakes had been predicted.

This is why Giardini believes that models predicting no magnitude 9 earthquakes for Central America, Tonga and Japan based on the age of the crust now have to be reassessed. He assumes that such major earthquakes will also have to be taken into account for those regions on the risk map.

At the lecture, Giardini compared the Tohoku earthquake with the 6.3 quake that hit Christchurch on February 22. The epicentre of the Christchurch earthquake was closer to the Earth’s surface, and the rift zone was directly underneath the city. This is why the acceleration of the Earth and thus the forces acting on the buildings were stronger, despite the fact that the energy of the magnitude 9 quake in Japan was 20,000 times greater. In both cases, however, the damage caused to new

buildings by the earthquake was astonishingly minor. Responding to a query, the ETH Emeritus Professor Hugo Bachmann, an expert in earthquake engineering, explained that this is primarily thanks to the sophisticated earthquake engineering methods used in the two countries. Civil engineers in New Zealand revolutionized seismic engineering in the 1970s, he explained, by incorporating ductile areas in the supporting structures of buildings which bend during the tremors of an earthquake, thus protecting the building from collapse. From the 1950s onwards, Japan on the other hand used more massive construction techniques, incorporating more and more cement and reinforcement in the supporting structures of buildings. However, after the major earthquake in Kobe in 1995, the realization set in that this can also be counterproductive for several reasons. “Japan then adopted the technology used in New Zealand, which has now spread across the globe”, said Bachmann.

Progressive in terms of tsunami and earthquake research

In general, Japan is considered to be very well prepared for earthquakes and tsunamis. The early warning system also worked very well on March 11. Warnings were given eight seconds after the seismic waves reached the coast and between 20 and 60 seconds before the destructive waves of the earthquake reached land. Large sections of the coast are protected against tsunamis by barriers, explained Giardini, but in Sendai these protective barriers were not high enough. Based on what we know at present, the more than ten-metre high tsunami flooded the diesel generators designed to cool the nuclear power plants in an emergency and washed away the diesel tanks located outside of the protected reactor area.

Indicators as far back as 2001

However, a study carried out by a team of Japanese researchers back in 2001 already indicated that unusually high tsunamis – and thus presumably also earthquakes with a magnitude of more than 8.2 – can take place in the region every 800 to 1000 years. At the time, scientists analyzed tsunami deposits dating from the year 869 and created models of the tsunami that caused the deposits. The models suggested that an earthquake with a magnitude of 8.3 had taken place and had generated a tsunami with a maximum height of eight meters. Like the most recent earthquake, the tsunami waves are thought to have reached the coast of Sendai 30 minutes later.

For Giardini, one of the important points going forward is that even more extensive analysis of potential catastrophe scenarios is needed. This is because even when the Niigata earthquake struck the west coast of Japan in 2007, causing problems in the Kashiwasaki-Kariwa nuclear power plant complex, the periphery infrastructure outside of the reactor (such as water and power lines as well as access roads and diesel tanks) was damaged by the quake. “Comprehensive risk analysis at the level now planned by the Swiss government is necessary both in Japan and on a global scale”, Giardini told ETH Life.

Earthquakes in Japan

Japan has in-depth engineering knowledge in the field of seismic engineering and the country also boasts the world’s largest earthquake simulator. The simulator can be used to test building components and buildings of up to six floors high in a realistic environment. Japan also has a sound knowledge of its tectonic faults and is a leader in tsunami protection measures. In the last century, there were 24 earthquakes on Japan’s east coast that had a magnitude higher than 7. Such events take place there every four years on average and had also preceded the disaster of March 11. This is why Giardini suggests that quakes in excess

of magnitude 7 should perhaps in future be expected to be even stronger and that, as a precautionary measure, critical infrastructural locations such as nuclear power plants as well as hospitals and ports should remain on raised alert for a whole week.

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