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Ten Years After the 2011 Tohoku, Japan Earthquake and Tsunami

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The Tohoku region of northeast Honshu, Japan, was struck on 11 March 2011 by a huge earthquake (Risk Frontiers, 2011, 2012) which occurred offshore and generated and a huge tsunami (Figure 1). The earthquake magnitude was 9.0, the strongest ever recorded in Japan, and the tsunami height of 39m at Miyako was also the largest ever recorded and travelled inland as far as 10 km to Sendai Airport. The tsunami flooded an estimated area of approximately 560 square kilometers. The waves overtopped and destroyed protective tsunami seawalls at several locations, and the massive surge destroyed three-story buildings in which people had gathered for safety.

The relative motion across the offshore plate interface at shallow depths that caused the earthquake reached 50 metres. The elastic rebound of Japan's northern Honshu coastline caused it to move east by about 2.4 metres and subside by about 0.6 meters. Strong ground motions extended all the way south to Tokyo, and tsunami heights reached 10 metres or more over hundreds of km of coastline (Figure 1). Over 20,000 people were reported as dead or missing, 92% by drowning due to the tsunami. Tsunami inundation caused meltdowns of nuclear reactors at the Fukushima Nuclear Power Plant. The event was a vast cascading disaster that occurred despite extensive efforts at preparedness against earthquakes and tsunamis in Japan. This briefing explores the causes of these breakdowns in preparedness.

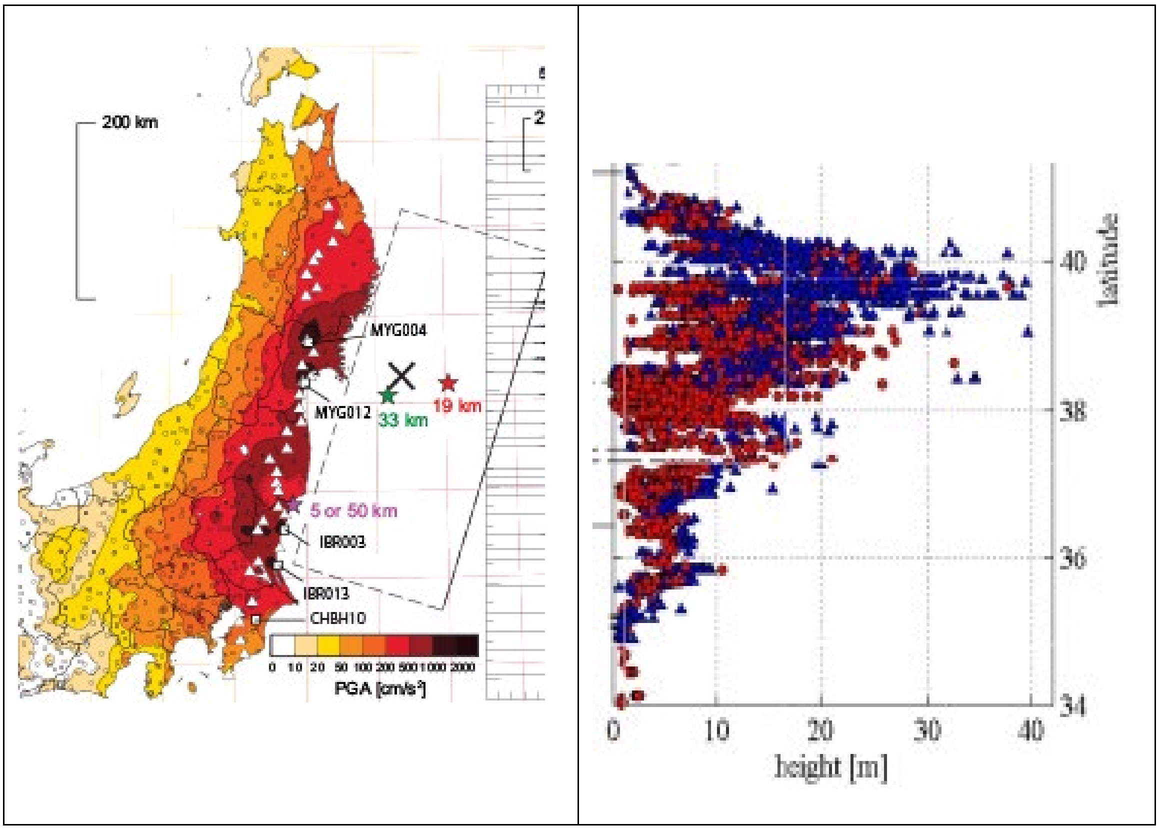

Figure 1. Left: Rectangular fault plane offshore, and map of peak acceleration, dark red is 0.5g or larger. Source: Furumura et al. (2011). Right: Tsunami inundation (red) and runup heights (blue) along the coast. Source: 2011 Tohoku Earthquake Tsunami Joint Survey Group.

Breakdown of Information Flow Before the Earthquake

The first breakdown in information flow occurred well before the earthquake. Research in 1991 had found evidence of a similar huge tsunami (the Jyogan Earthquake and Tsunami) in 869 (Minoura and Nakaya, 1991), causing inundation similar to that of the 2011 earthquake in the region east of Sendai (Minoura et al. 2001). A hazard assessment that embodied this information, prepared in 2002 by the Headquarters for Earthquake Research Promotion (HERP), was disregarded by the Cabinet Office, acting as regulator of the Tokyo Electric Power Company (TEPCO), on the basis that it was unreliable (Risk Frontiers, 2020).

In 2008, TEPCO made what it refers to as "trial calculations" of maximum wave heights based on the 2002 HERP report and wave source models for the 869 Jyogan tsunami based on the models of Satake et al. (2008). The estimated maximum wave heights from these trial calculations were significantly higher than previous estimates: up to 10.2 m at Fukushima Unit 1 and up to 8.2 m at Fukushima Unit 2. The estimated maximum run-up height at the southern portion of the Fukushima Unit 1 site was estimated to be 15.7 m, similar to the 15.5 m inundation height at the plant from the March 11, 2011, tsunami.

However, TEPCO did not trust these calculations, and revised its maximum tsunami wave height estimates in 2009 using the Japan Society of Civil Engineers (JSCE, 2006) methodology with updated bathymetric and tidal data. The new estimates were 6.1 m for Fukushima Unit 1 and 5.2 m for Fukushima Unit 2. TEPCO raised the elevations of seawater pumps at Fukushima Unit 2 based on this new estimate.

In 2009, TEPCO and other nuclear plant operators requested that JSCE undertake additional reviews of tsunami source fault models and associated methodologies. This review was estimated to take about 3 years (2009-2012), which in the event was too late. In a decision that strained credulity, TEPCO officials were acquitted of professional negligence in the Fukushima Nuclear Disaster on September 19, 2019 (Risk Frontiers, 2020), despite the fact that the Japanese government had been successfully sued in 2017 for negligence by private citizens affected by the disaster on the grounds that the tsunami and ensuing nuclear disaster were foreseeable. This ruling echoed the conclusion reached by an independent parliamentary investigation (National Diet of Japan, 2002), which described the Fukushima Daiichi meltdown as a "man-made" disaster, and stated that "The Fukushima nuclear power plant accident was the result of collusion between the government, the regulators and TEPCO, and the lack of governance by said parties." It is estimated that decommissioning of the Fukushima nuclear plants will take another 30 to 40 years and cost an estimated 13 trillion yen ($AUD160 billion).

The lessons learned from this experience by a committee of the U.S. National Academy of Science (NAS Committee, 2014) are that:

- Licensees and their regulators must continually seek out new scientific information about nuclear plant hazards and methodologies for estimating their magnitudes, frequencies, and potential impacts.
- Nuclear plant risk assessments must incorporate new information and methodologies as they become available.
- Plant operators and regulators must take timely actions to implement countermeasures when such new information results in substantial changes to risk profiles at nuclear plants.

Breakdown of Information Flow at the Time of the Earthquake

When the 2011 event occurred at 14.46 JST on 11 March, the Japan Meteorological Agency (JMA)'s initial estimate of the magnitude, released 3 minutes after the earthquake, was 7.9. JMA issued a major tsunami warning to the coasts of Iwate, Miyagi and Fukushima prefectures with estimates of 3 m, 6 m and 3 m, respectively. After the tsunami was observed at offshore tsunami buoys, JMA revised the contents of the warning with estimates of 3 m, 6 m, over 10 m, 6 m, 4 m and 4 m to the coasts of Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba prefectures, respectively. Receiving the tsunami warning from JMA, some residents thought that they were safe based on the 3 m estimate and did not perceive that they needed to evacuate because they felt safe behind a 10 m seawall. In several communities, the radio or speaker system did not work because of the blackout caused by the earthquake. Research presented by Japanese national broadcaster NHK on 8 March 2021 showed that there was ample time for evacuation given a clear understanding of its necessity, and that surviving the tsunami was contingent upon following the communication chain of a decisive leader and on having the physical ability to evacuate; many of the victims were over the age of 65.

JMA has now expanded its seismic and tsunami monitoring network by installing broadband seismometers and an offshore tsunami monitoring system to increase its capability for quicker and more accurate estimation of earthquake magnitude and tsunami wave heights. It is still difficult to determine a precise magnitude within 3 min for earthquakes with a magnitude 8 or more and for ‘tsunami earthquakes’ that generate much larger tsunamis than their magnitude would suggest. For such cases, JMA has introduced methods to quickly highlight the possibility of underestimation in magnitude estimation and issues an initial tsunami warning based on the largest earthquake fault expected in the area where the earthquake was triggered. However, there are still limitations on the reliability of technologies that can be used in a very short time. Tsunami warning information can inform people that they are in danger, but it cannot guarantee their safety. The most important lesson is that people should not wait for official information to act, and that strong ground shaking is the first alert to take action.

Breakdown of Buildings, Infrastructure and Lifelines After the Earthquake

More than 120,000 buildings were destroyed, 278,000 were half-destroyed and 726,000 were partially destroyed. The direct financial damage from the disaster is estimated to be about $200 billion dollars (about 17 trillion yen), according to the Japanese government. The total economic cost could reach $AUD3000 billion, the World Bank estimated, making it the costliest natural disaster (in non-normalised terms) in world history.

The number of completely collapsed and washed-away houses amounted to 76,000, and the number of those with half and partial damage was over 244,000. Following the earthquake, 345 fires occurred in 12 prefectures, including cases where the tsunami triggered the fire. Most of the destruction of buildings in the coastal areas was caused by the tsunami, not by ground shaking, and there was relatively little damage to buildings inland. It is remarkable that only 1,600 people died from building damage and other effects in the vast area that experienced strong ground shaking depicted on the left side of Figure 1; the other 18,400 people were drowned in the tsunami.

Infrastructure damage was widespread. Reported damaged included 3,546 locations along roads, 71 bridges and 26 parts of the railway system. This damage had strong effects on the recovery as well as on general economic activity. However, due to long term disaster preparedness activities, the hundreds of trains in operation, including the Tohoku bullet train, were able to make emergency stops safely without any deaths or serious injuries.

Lifeline infrastructure including electricity, water supply, sewage systems, and gas lines was also damaged. Although such services were soon restored in most of the damaged areas, the coastal areas most heavily damaged in Tohoku were without these services for extended periods of time. Down time of lifelines continued for several weeks in many places. Much more time was needed to restore services in the areas with tsunami damage and soft foundations. Damage to roads, railways and lifelines resulted in immediately insufficient supplies of food and gasoline to the impacted areas, and impeded rescue activities. Secondary effects then resulted, including impacts on the physical and psychological conditions of evacuees.

The largest and most long-lasting impact of the earthquake and tsunami has been at the Fukushima nuclear power plant and surrounding regions. These impacts include nuclear contamination of soils and sea water, and evacuation of a large number of residents in the surrounding areas. These residents are still recovering from the disaster, and there are still about 50,000 evacuees who lost their homes living in temporary housing. Although some parts of the evacuation area affected by radiation have been approved for resettlement, they have a bleak environment and it may be a long time before they are resettled. This harrowing experience has revealed shortcomings in the government's risk management and information disclosure. The combination of the physical impacts of the earthquake and tsunami with health, psychological, and social problems caused by the Fukushima nuclear plant accident generated a very serious and complex situation that is still being resolved.

Breakdown of Information Flow After the Earthquake

Fukushima Central Television (FCT), with a four-minute delay, broadcast a video that showed a thick white cloud emerging over the Fukushima plant, but the origin of this white cloud went unexplained for several weeks. TEPCO was providing preliminary radiation numbers within 24 hours of the accident, together with real-time updates on conditions at the reactor. The problem initially was not a lack of information but a lack of communication. It took a long time for TEPCO and the government to acknowledge that the white cloud was likely due to hydrogen explosions, which probably indicated partial meltdowns of the affected reactors, and they resisted the use of the word "meltdown" of the reactor core until visual evidence of it was obtained years later by robots operating within the reactors.

Following the 11 March 2011 nuclear catastrophe, massive amounts of radioactive materials including Iodine 131, Cesium 134, Cesium 137, and Strontium 90 were released into the atmosphere. The government's System for the Prediction of Environmental Emergency Dose Information, known as SPEEDI, began generating predictions of the spread of airborne radioactivity almost immediately after the disaster, but the first public release of this information was delayed for almost two weeks. Lacking this or any other guidance, residents of at least one evacuating community, instead of moving away to safety, headed straight into the path of the fallout.

Nuclear reactor meltdowns forced the Japanese government to issue evacuation orders for all residents living within a 20 km radius of the Fukushima Daiichi power plant that were later extended. Local residents were told to evacuate but not why; they did not know where to go, or how long they would be away from their homes. Thousands of people were affected by the nuclear fallout because a proper evacuation plan and contingency measures were not in place. Japanese scientists hesitated to release information that was uncertain, but almost everything was uncertain after the accident. But most people did not demand perfect information; they could accept uncertainty, as long as things were carefully explained, and just wanted to know.

The Japanese government tried to convince its people that things were under control at the Fukushima plant and that radiation levels posed no health threats. But this attitude backfired: poor risk communication greatly amplified uncertainty. Rather than finding reassurance, nuclear evacuees felt they had been deceived by the government and the nuclear industry. In the inevitable confusion of a disaster scenario, the contradictions in the discourse of the medical community did not help. The government's unexplained—and seemingly arbitrary—raising of safe radiation-exposure levels for schoolchildren from 1 millisievert to 20 millisieverts per year was particularly damaging. The government's tendency to withhold information and downplay radiation risk has had lasting consequences across post-disaster Japan. As a result, trust in the authorities was badly damaged, and profound disbelief of health policies still permeates public perceptions.

Problems with Reconstruction of Tsunami Defence

The Kamaishi tsunami breakwater was the highest in the world and was designed to protect the densely populated area in Kamaishi located at the end of the bay. Its construction started in 1978 and was completed in 2009, requiring an investment of almost 30 years and 120 billion yen (one billion dollars). But even this barrier could not protect its citizens from the 2011 tsunami, although it earned them a 6-minute delay before the tsunami penetrated Kamaishi, and reduced the tsunami height by 40% (from 13.7 m to 8.1 m) in the harbour. People in Kamaishi felt well protected before the event, but the 2011 tsunami caused 1253 fatalities in the city.

Coastal infrastructure such as breakwaters and seawalls cannot always protect life and property, and even great seawalls can fail. It is recognised that in order to save lives in the face of a 1000-year average recurrence interval (ARI) tsunami, there are no ways other than quick evacuation and rescue. Seawalls should be designed with the assumption of overtopping and destruction, and communities should not rely on coastal infrastructure alone for protection.

A new paradigm in coastal structural design has been developed that sets the height of seawalls to ensure their performance to a potential tsunami level of up to a 150-year ARI. The plan is that people should live in higher places, while they work in the coastal areas because low-lying coastal areas are still important for ports, fishing and other commercial activities. Therefore, coastal dykes, coastal forests and other facilities should be reconstructed so that they can protect the economically important coastal areas against a 150-year event.

However, implementation of this design paradigm has triggered conflict and debate. Many coastal communities on low-land devastated areas are thus moving uphill by applying for relocation and buy-out. This scattering of residential areas will isolate people and weaken community connections, and consequently, undermine the community's sustainability with shrinking population in rural areas. The purposes of the new seawalls remain unresolved in the minds of many residents.

As observed in devastated areas in Tohoku, tsunami flow depths over 2 m have the potential to severely damage houses. High rise reinforced concrete buildings with robust columns and walls can withstand tsunami flow depths over 2 m and can be used for vertical evacuation. However, at least eight reinforced concrete or steel construction buildings were overturned or washed away, leading to revision of the requirement for structural design of tsunami evacuation buildings, specifically focusing on the tsunami loading effect. It has been determined that school buildings should have similar construction requirements, in order to ensure children's safety. Teachers, parents and children should have more opportunities to learn about their risk and how to survive in emergency situations.

Problems with Risk Communication

The government and some scientists, faced with communicating this disaster, were very concerned with protecting the public. They did not want to cause a panic or spread fear, but in trying to avoid doing so, they withheld information, and this spread more fear. The official tendency toward reassurance at all costs reflected a problem that existed well before the accident: the idea of absolute safety. The nuclear industry wants people to believe that nuclear power is absolutely safe and works very hard to make that case. The Fukushima disaster showed the risk of preaching absolute safety.

There is a perception that this myth of absolute safety has dominated the policies of the Japanese government and prevented it from applying improvements to its nuclear power plants, and that the mindset needs to change from one of absolute safety to one that recognises the inevitability of future natural disasters and aims at anticipating them and reducing their impact, incorporating the lessons of past mistakes.

The Tohoku earthquake and tsunami and the resulting damage shocked all social sectors, including the research community. Recent findings of scientific research were not transferred to improving the protection of nuclear power plants and other important facilities, highlighting problems for the decision-making systems within society. There are barriers among different fields that hamper information flows between disciplines, and single academic fields cannot resolve challenges of this scale, for which multi-disciplinary approaches are necessary. The most important lesson for life safety from the 2011 Tohoku earthquake is that public information and public education are the most important part of tsunami hazard management.

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