The March 2011 Japan tsunami

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Abstract
The March 11th 2011 Tohoku-iki earthquake was the fifth largest on Earth in the last 50 years, it created one of the most devastating tsunamis in history. Dave Tappin describes the background to the tsunami and its impact based on his research on tsunamis and visits to Japan over the past three months.


Figure 1Photograph of tsunami warning sign (Photograph by D. R. Tappin 2011).

The earthquake and tsunami that struck Japan on Friday March 11th brought home yet again the devastating impact of natural hazards such as earthquakes, volcanic eruptions, storms and floods that can occur with little or no warning. Japan is a country particularly vulnerable to geological hazards because it is located on the famous 'Pacific Rim of Fire'. Written records that extend back over one thousand years provide an amazing historical context allowing hazard frequency to be relatively well understood. These events are not new to Japan, the last major earthquake was in 1995,when Kobe was destroyed and 6,500 people lost their lives.


Figure 2 Photograph of destruction of Minamisanriku, northern Honshu (Photograph by D. R. Tappin 2011).

Japan is thus well prepared with a sophisticated warning system for earthquakes and tsunamis that is activated within minutes of the events, with the warnings transmitted over TV, radio and mobile phones as well as speakers located on the street – those who saw the TV footage of the Japanese Parliament discussing the earthquake as the building shook, might not be aware that the Japanese text on the screen was in a fact the earthquake warning. Practise drills take place regularly and street (and pavement) signs guide people to safe refuges (Figure 1).


Figure 3 Photograph of tsunami destruction – Yiagi Port (Photograph by D. R. Tappin 2011).

Despite the background knowledge and precautions, the March 2011 earthquake when it occurred was much larger than predicted and, although there was little earthquake damage, the associated tsunami was much larger than many of the built defences and evacuation strategies could cope with (Figures 2 and 3).

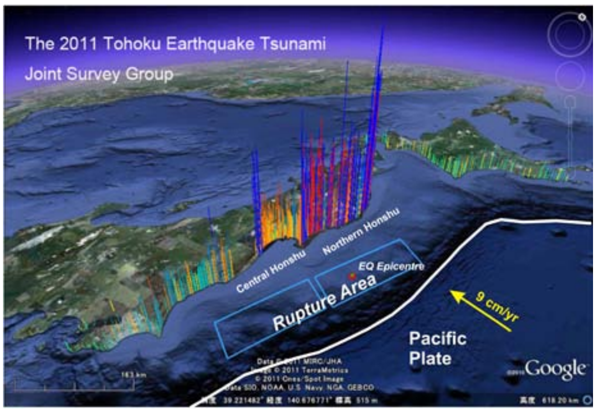

Figure 4 Image of the Japan convergent margin. White line - convergent margin; vertical lines – runup heights (Google Earth background and Tohoku Joint Survey Group)

Figure 5

The event demonstrates therefore that although our knowledge base is good, it is the application of this knowledge that counts and this is dependent upon people as much as on technology.

The March 11th Japan tsunami was huge, its' estimated cost is between 120 and 235 billion dollars. 300,000 are still homeless, 130,000 are still in shelters. 19,000 cars were destroyed in Myage Prefecture alone. 26,000 fishing boats wrecked. Inundated farmlands will take 2-3 years to recover from salt water inundation. The reconstruction is estimated to cost $12 billion. A recent comparison is with the Boxing Day event in the Indian Ocean of 2004, when over 220,000 people died in the tsunami that struck Thailand, Indonesia, India and Sri Lanka. The Japan earthquake was of a similar size, a magnitude (M) 9. It is what is called a Great Earthquake and was the largest ever recorded in Japan. Elsewhere, there was a M9.4 that struck Chile in 1960, in 1946, the Aleutian Islands were struck by a M9.3, in 1837, when Charles Darwin visited Chile, it was struck by another M9.3 and in 1964 Alaska experienced a M9.1 event. So the Japan earthquake is certainly in the top five.

The basics of the earthquake rupture are well established. Japan lies along a convergent plate boundary (Figure 4). To the east, the Pacific Plate is subducting westward at a rate of -~9 cm/year. At 1446 local time on Friday March 11th the plate boundary ruptured, moving Japan 2.4 cm eastward closer to America. The Pacific Plate moved ~20 m west. The rupture was 400-500 kilometres long and the vertical movement 5-8 metres. Earthquakes are common along the plate boundary but historically, none greater than magnitude 8 had previously been experienced. Thus the magnitude 9 was unexpected. Located 60 km offshore, the earthquake itself was relatively benign with regard to ground motions affecting the onshore areas, as there was little damage. An offshore earthquake however poses a major hazard as far as tsunami generation is concerned. The vertical motion of the seabed propagates upward to the ocean surface where it creates a ‘step’, subsequent collapse of the step results in a wave that travels outward from the source at hundreds of kilometres an hour. If the earthquake is larger than a M 7, a tsunami warning is usually given although the associated tsunami may be small. A magnitude 9 earthquake is 60 times larger than a 7 and locally can create a tsunami with runups of 10’s of metres. Within 20 minutes of the March 11th earthquake tsunami waves of 20-30 metres were striking the nearest coastlines.

Within 60 seconds the earthquake was identified as major and warnings issued, ground motions were felt in Tokyo, 350 kilometres to the south within 90 seconds. A tsunami warning was issued within minutes. The problem in some areas was that the predicted tsunami run up heights were too low. In the scientific press this has been much commented upon, but it should be realised that there were both good and bad aspects of the warnings. Firstly, the warnings were timely. For earthquakes it is important for people to expect the ground shaking so that they can take action. Most new concrete buildings in Tokyo are built to be earthquake resistant, so with warning people can get to cover under tables for example or get out of lifts (there may be power failures). With an earthquake source so close, horizontal evacuation from a tsunami may be difficult, so in many places there is vertical evacuation to tall buildings. The northern coast of Honshu is quite mountainous and the coastline is rather like Cornwall with coastal valleys and ‘rias’ (Figure 4). It is particularly vulnerable to tsunami because immediately offshore the seabed drops away rapidly, leading to rapidly moving tsunamis and the valleys funnel the tsunami landward, leading to very high runups that may be 40 m (Figure 4). Tsunamis are not unusual. In 1933 there was an earthquake tsunami that killed 3,000 and in 1896 27,000 died in a similar event; runup heights for these events were measured in tens of metres, in one location 40 m. Because of the historical knowledge from these events, it was known that safe havens were identified high above the coastline and, where, possible tall buildings were identified as refuges.

It was father south of the north Honshu highlands, in Central Honshu, that the underestimate of tsunami wave heights was most grave (Figure 4). From historical earthquake records, the largest previous events were about M8. Thus tsunamis from these were believed to be the worst case scenarios. Unfortunately, the historical Great Earthquakes from other countries such as Indonesia and Chile were not taken into account, most significantly, the earthquake and tsunami of Boxing Day 2004. This too took place in a region where M9 earthquakes were unexpected. It led to a re-evaluation of where these large events might take place. Because of the timescales over which these Great events occur it was recognised that historical records were an inadequate basis for prediction and that the models on which mitigation strategies were based were incorrect. It was proposed therefore that many convergent margins, hitherto believed ‘safe’ from Great earthquakes may indeed be vulnerable. In the Pacific it led to a major revision and overhaul of the regional system that issues tsunami warnings in the ‘far-field’, that is where the source earthquake is in one location, say off Chile, and the tsunami will strike another far distant, such as Hawaii or Japan. In this instance the tsunami travel time from source to impact is hours – perhaps 14 hours to Hawaii and 22 to Japan, and the tsunami wave is tracked all the way across the ocean by wave buoys positioned at strategic locations. Thus there may be hours in which local populations can be warned and coastal areas evacuated if necessary.

Unfortunately, in Japan the new data on where Great Earthquakes may happen was not considered. In addition, empirical evidence from prehistorical events, based on geological data, such as sediments laid down from tsunami (Figure 5), was also not taken into consideration. The result was that in the low lying areas to the south of northern Honshu the tsunami wave was up to twice as high (12 m) as anticipated and defences such as ‘tsunami walls’ were overtopped, and refuge buildings too low.

There is a famous quote about earthquakes that states that these events do not kill people – buildings do. In Japan this has been taken to heart and all modern buildings are constructed to withstand earthquake shaking. As has been learned from recent events in 2004 and that of Japan 2011 in the instance of tsunamis, it is the real killer. They are also very destructive, because it difficult to build low-storey tsunami-proof buildings. Most buildings destroyed in Japan were of wood. In the future there is no doubt these experiences will be taken into consideration, but to mitigate against tsunami in low lying areas is not easy. With the 2011 event the tsunami took 75 minutes to reach the coast of the Sendai Plain coastline in northern Honshu. The tsunami penetrated ~5 km inland. A tsunami travels across land at speeds of up to 60-70 km/hour. Thus there is time to warn, but evacuation is problematic, especially at night. To move across ground to safe havens is difficult, roads are not always straight or lead directly to places of safety. Congestion and breakdown, not to say panic, are impediments to rapid travel. Vertical evacuation is feasible, but the tsunami run-up height estimates have to be accurate. Fortunately, in Japan as we see from the videos, there were many roads that were built on embankments that were above inundation level, and these saved many lives. The area is mainly agricultural, thus population densities were low.

During my two visits to Japan, the resilience of the Japanese people was astounding. Affected areas where there was massive destruction were like giant reclamation plants (Figure 6). Debris was being cleared and sorted. Damaged houses were being repaired. There was an air of amazing communal responsibility; where the tsunami had passed through, nothing exposed had been touched, bicycles lying exposed, and intact, in paddy fields, pots and pans and all the trivia of domestic life in houses, all remained in place as if the tsunami had passed through yesterday. The next phase of reconstruction will be difficult. Major questions remain. Should vulnerable areas be rebuilt and repopulated, what mitigation is required where populations are vulnerable? Most importantly what magnitude of earthquake and tsunami should be mitigated against in the future, because there is no doubt that, in Japan, they will occur again.

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The event is too recent to have many publications, but these websites are a source of material:

http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1713&Itemid=2365&lang=en