CoreLogic

10 Years Later

The Great Tohoku Earthquake

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Introduction

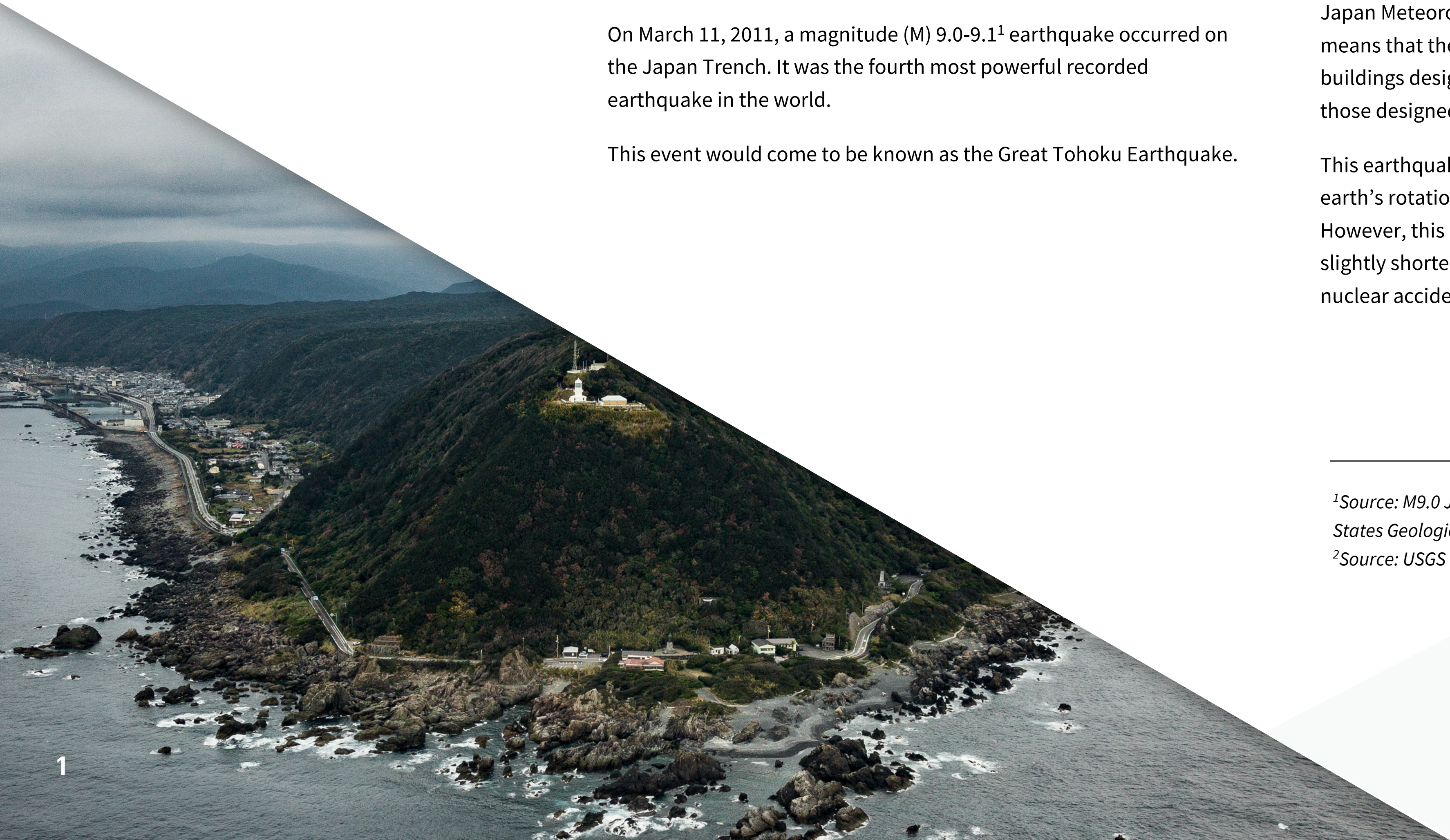
Located in one of the most seismically active regions of the world, Japan is no stranger to earthquakes. It sits in proximity to four tectonic plates, four distinct subduction zones, from Nankai Trough, Sagami Trough, Japan Trench and Kuril Trench, in addition to experiencing earthquakes from crustal faults.

On March 11, 2011, a magnitude (M) 9.0-9.1[1] earthquake occurred on the Japan Trench. It was the fourth most powerful recorded earthquake in the world.

This event would come to be known as the Great Tohoku Earthquake.

The event generated a massive tsunami and triggered over 1,000 aftershock events, some reaching M7[2]. A fourteenth of the landmass of Japan experienced at least severe ground shaking, or a Modified Mercalli Index (MMI) of 8, based on a 12-point scale used in the scientific community. This is equivalent to a 6+ on the Shindo scale, used by the Japan Meteorological Agency to measure ground shake intensity. This means that the event was strong enough to cause serious damage to buildings designed to a low-seismic resistance, with less damage to those designed for seismic resistance.

This earthquake even shifted the earth on its axis—and increased the earth's rotational speed, thus shortening the day ever so slightly. However, this earthquake was most notable for its huge tsunami—just slightly shorter than the Statue of Liberty in peak wave height—and its nuclear accident at the Fukushima Nuclear Power Plant complex.



[1]Source: M9.0 Japan Meteorological Agency (JMA) and M9.1 United States Geological Survey (USGS)
[2]Source: USGS

TSUNAMI

The tsunami loss from the event was substantial; from a modeled perspective, CoreLogic estimates that 15% of the total physical property insured loss would have been caused by tsunami.

The potential for tsunami damage in Japan has been known for a long time, with most of the Eastern and Southern coast of Japan susceptible to tsunami heights contributing to losses.

Typically, the larger the earthquake the more important the tsunami loss component. This is due to the larger area of vertical slip displacing larger amounts of water, triggering a larger tsunami, and usually there is only concern of significant threat of tsunami where the earthquake magnitude is greater than M7.5. The distance of the Japan Trench to the shore plays an impact on this, where the proportion of tsunami risk is roughly equivalent to that of ground shake in the more extreme return periods represented by the tail of the exceedance probability curve.

Fishing boat ashore post-Great Tohoku Tsunami, *Source: ShutterStock*

ISSUE OF POWER GENERATION AND NUCLEAR ACCIDENT

Power failures caused by damage to power facilities and concerns over aftershock activity contributed greatly to the damage and raised important questions on power generation and power redundancy in the Japan grid. Of greatest concern was the Fukushima Daiichi Nuclear plant, where both ground shaking and tsunami heights (reported at 13-17m) were in excess of design standards in multiple facilities. The failure of the residual heat removal (RHR) cooling facilities of three reactors was also caused by the tsunami, leading to the cores being largely melted and causing an official nuclear accident.[3]

In total, the event and subsequent failure of nuclear facilities were estimated to have caused in excess of $235B (or ¥25 T) in economic damage[4] at the time. From a modeled view of insurable property based on exposure today, the ground up loss would be in the region of $140Bn (Yen 15 Trn) with a gross loss of around $40Bn.[5] (Yen 4.2 Trn).

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[3] *Source: World Nuclear Association*
[4] *Source: World Bank*
[5] *Source: CoreLogic, based on proprietary high-resolution Industry Exposure Database*

CoreLogic estimates the event would cost $140Bn (or ¥15 Trn) in ground up insured property damage if the event occurred today

Of this loss, 15% comes from tsunami

EARTHQUAKE RUPTURE ZONE

Though often earthquakes locations are presented in terms of a point, or latitude/longitude, earthquake ruptures occur over an area, known as the area of slip. The larger the earthquake, that is energy released, the larger the area affected.

As shown in Figure 1, the M9.1 event saw an area of non-uniform slip covering 220km x 400km. This slip cascades down the fault in what is often called unzipping, in earthquakes of this magnitude, the process can take several minutes. Putting this into perspective, that's bigger than the entire island of Hokkaido, or the country of Portugal.

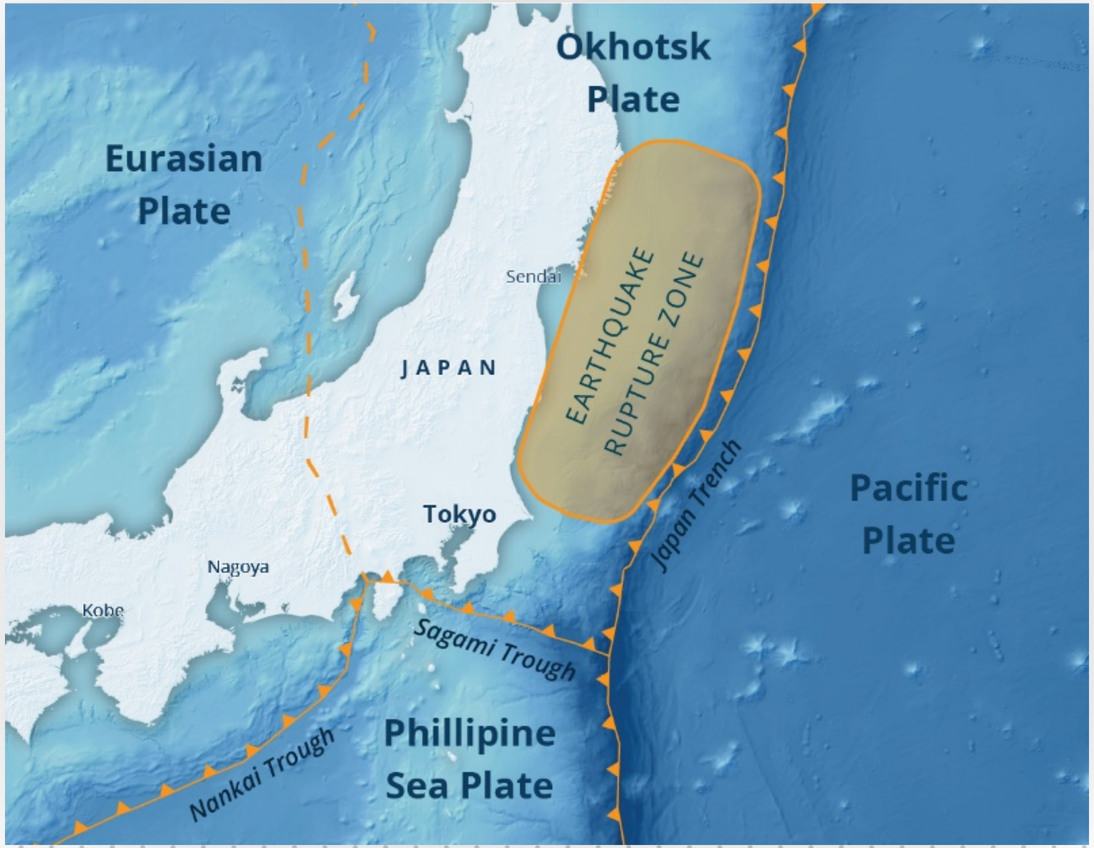
Prior to 2011, the maximum earthquake thought to be possible in Japan was M8.5, according to the Japan government model from the National Research Institute for Earth Science and Disaster Resilience (NIED). Given the logarithmic nature of earthquake magnitudes, the Great Tohoku event that occurred was around 20 times stronger (in terms of energy released) than this theoretical maximum.

Looking back at the initial event response guidance in the industry for estimating losses immediately after the event, the recommendation was to take the modeled loss from one event, add it to the loss from a second event, and double it. This indeed was an event that caught the seismological community and the re/insurance industry off guard. There has been hot debate on whether this event was indeed a true black swan event, or more a murky grey coloured swan.

> **The area of slip from the M9.1 event was bigger than the entire island of Hokkaido, or the country of Portugal**

> **The Great Tohoku event was 20 times stronger than the theoretical maximum that existed in models at the time**

Figure 1. Tohoku earthquake Magnitude 9.0/9.1 March 11, 2011



Source: USGS, Esri, CoreLogic

How has the Great Tohoku event changed the outputs of models ten years later?

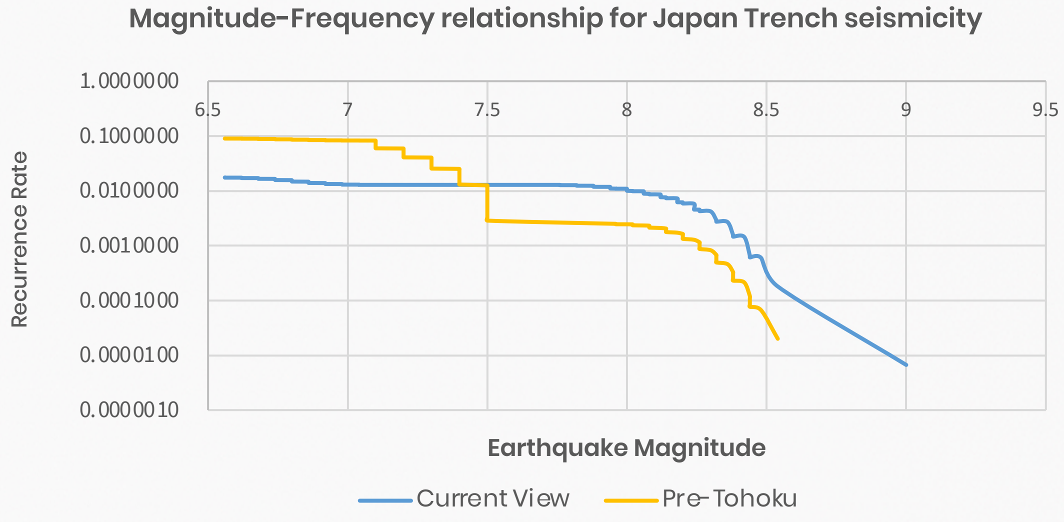
RISK CHANGES AFFECTING THE JAPAN TRENCH IN A POST-GREAT TOHOKU WORLD

The Pacific plate is subducting under the Okhotsk plate, and while the plates are locked, strain slowly builds up over time. Earthquakes occur due to a sudden release of this long-term strain build up. A main rule in seismology is that larger earthquakes occur less frequently than smaller earthquakes as the required strain for larger earthquakes needs to build up over a longer time period.

That M9 earthquakes can occur on the Japan Trench is now a verifiable fact. But, due to the strain build up that has been released from the Great Tohoku earthquake, the subsequent reduced amount of strain on the Japan Trench is expected to cause fewer such earthquakes to occur in the next few hundred years. There is a slight exception to this in that for a short period of time after the earthquake there are earthquake occurrence increases due to aftershocks.

These strain-related recurrence frequencies are typically captured in the time dependency aspect of the modeling, reflecting the best available recurrence as it stands today, not just the theoretical long term. So the overall time-dependent seismic budget of the Japan Trench is different when moving to a pre- and post- Tohoku view of risk.

Figure 2



However, the re-evaluation and allowance of earthquakes up to M9 that were absent from the pre-Tohoku modeled perspective of risk suggests that the inferred seismic budget for the Japan Trench has changed with an expected increase in risk due to allowing larger earthquakes to occur on the Japan Trench.

These factors trade-off to produce the outlook in Figure 2[6] showing the Pre-Tohoku and current view of the magnitude-frequency relationship on the Japan Trench. Here, the magnitude-frequency relationship of the current view in blue shows a smaller recurrence rate for smaller earthquakes up to M7.5. Then, the curves cross over, showing a higher recurrence rate of M7.5 and greater earthquakes. This shows the shift in both the absolute seismic budget, but also the shape of the distribution by magnitude size.

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[6] *Figure 2 is based on the CoreLogic implementation of the latest/previous NIED model*

How do these changes translate in to losses in the current view of risk?

Figure 3 shows us the proportion of modeled Average Annual Loss (AAL) by magnitude bin[7]. When looking at the loss potential from the earthquakes on the Japan Trench, we can see that ~25% of the risk comes from M7.5-M8.0 earthquakes, and ~75% of the risk comes from M8.0-M8.5 earthquakes. This makes sense when comparing against the higher frequency of these type of events in the blue curve in Figure 2, and shows us that these magnitude earthquakes are driving almost all of the loss in the models. Interestingly, even though the models now allow for earthquakes in excess of M8.5, the M8.5-M9.0 bin drives less than 1% of the risk. This is because while is the events are now possible (i.e. non-zero probability) in the models, the time-dependent probability of recurrence of such large earthquakes is too low to significantly drive losses.

It's important to note that the Japan Meteorological Agency (JMA) has included planning scenarios that capture more extreme events up to a M9.5 event on the Japan Trench for use in areas such as disaster management. The probability and uncertainty assigned to this type of event is outside the bounds of any probabilistic view of risk, and therefore typically not included in probabilistic models.

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[7]*Figure 3 comes from the CoreLogic implementation of the latest NIED model*

~25% of risk

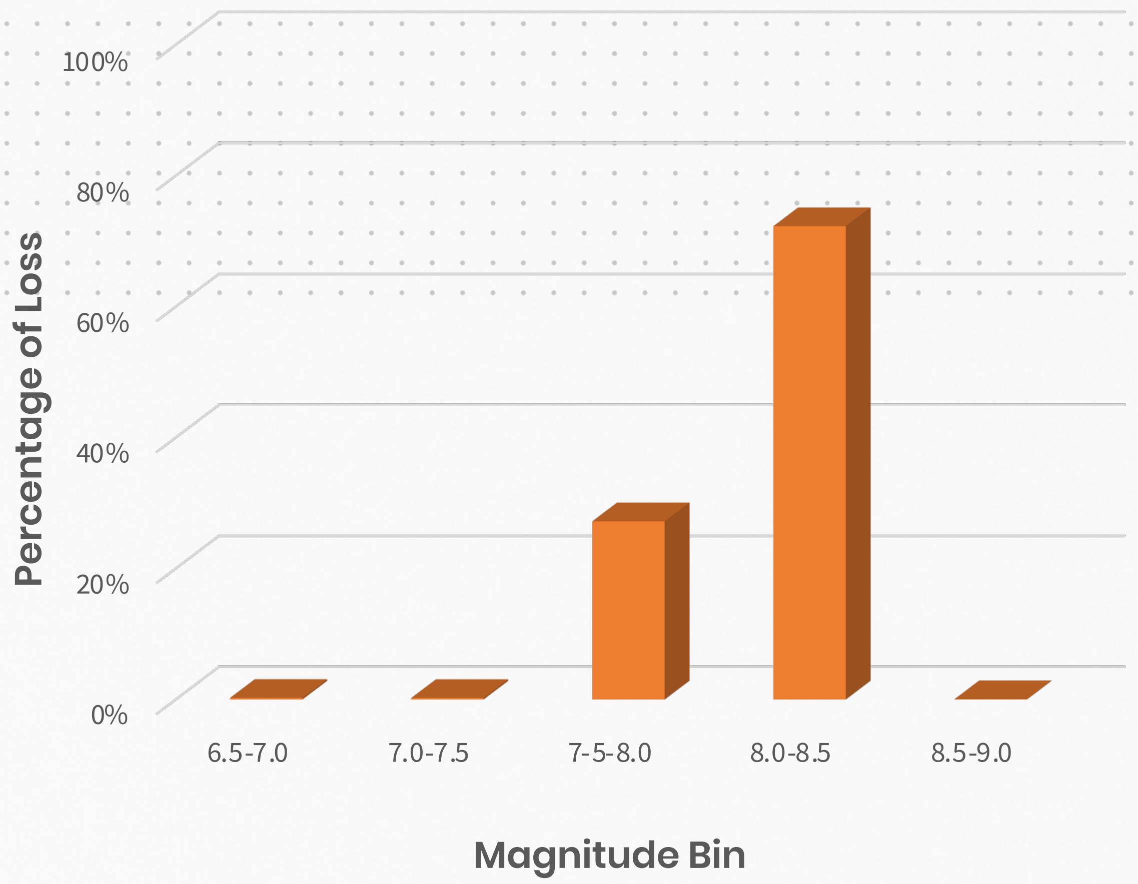
From M7.5-M8.0 earthquakes

~75% of risk

From M8.0-M8.5 earthquakes

Figure 3

Japan Trench losses by earthquake size Post Tohoku



RISK CHANGES AFFECTING JAPAN AS A WHOLE IN A POST-GREAT TOHOKU WORLD

The Great Tohoku Earthquake was an unprecedented event that caused massive damage and affected many lives. From an industry solvency perspective, diversified re/insurance companies were more than adequately capitalized as the majority of the building density and perceived risk in Japan is further south.

This is shown in Figure 4, where we show what drives the Japan wide ground shake risk. The NIED view is on the left[8], where the Nankai Trough dominates the entire loss curve. This is showing the risk perspective as it is now, however the same story can be seen pre-Tohoku.

Interestingly, when using the CoreLogic view of the hazard to look at the same risk, the Nankai Trough is less dominant at the average annual loss (AAL), but does still drive the majority of tail risk. In both views of the hazard, the same story is shown for the tail of the loss curve that drives conversations around capital adequacy and reinsurance purchase and pricing decisions.

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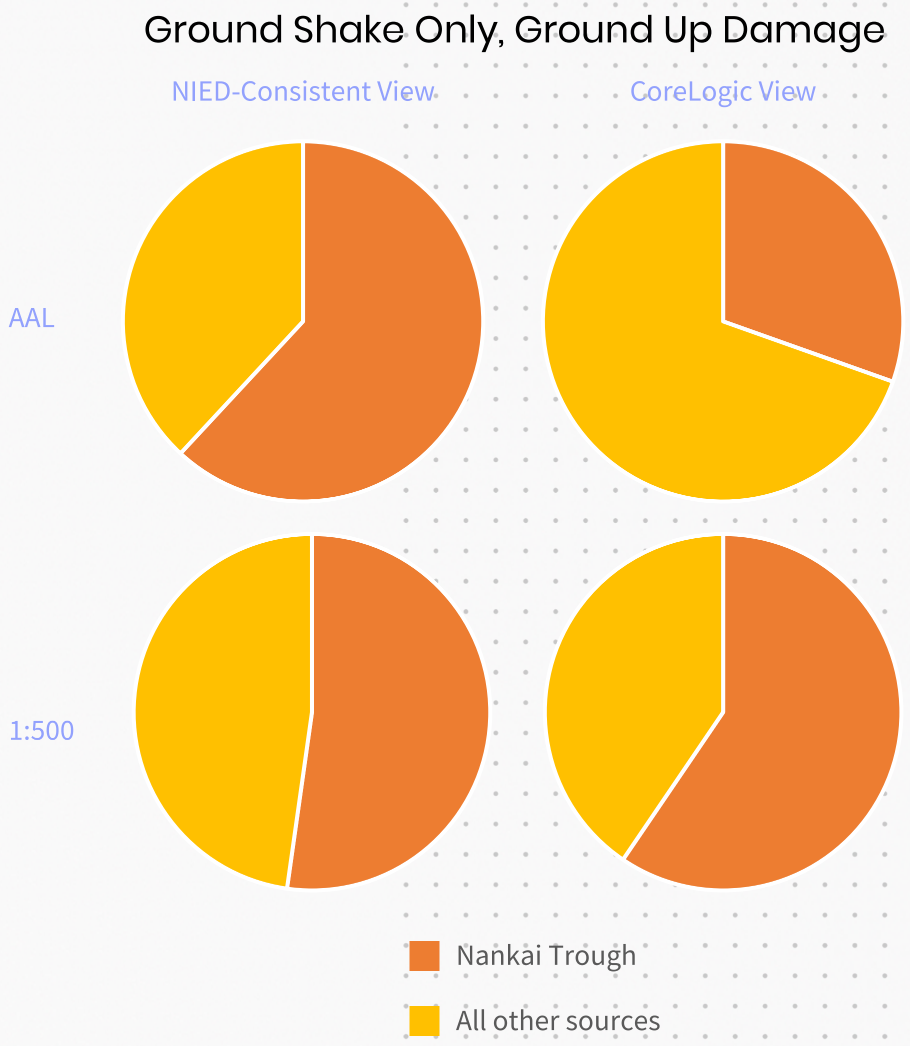
[8]*Figure 4 comes from the CoreLogic implementation of the NIED model, shown in comparison with the CoreLogic view.*

Figure 4. What drives japan earthquake losses



Recent Activity

On February 13, 2021 a M7.1[9] event on the Japan Trench served as a reminder of the risk posed. Even though it occurred nearly a full decade late, this has been officially recorded as an aftershock of the Great Tohoku earthquake by the JMA, perhaps a post-seismic slip event caused by stress change of the 2011 earthquake.

The M7.1 event was too small to trigger a sizeable tsunami, yet it did cause great alarm, concern and some damage. From an insurance perspective a low number of claims are expected in excess of earthquake deductibles.

An interesting observation was the noted power outages from power generation facilities; including coal burning power stations and nuclear facilities. The majority of power was brought up online within three days. However, the impact on certain industry lines is expected to have several weeks' worth of impact on industrial activity, with those most sensitive instruments, such as semi-conductors and intricate machinery affected most.

Typically, without physical damage to a facility this contingent business interruption is not covered under standard insurance policies. However, it poses an interesting challenge in further understanding business interruption risk in an increasingly connected and intricate world.

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[9] *Source: USGS*

What's Next?

Tohoku is the largest recorded insured loss from an earthquake (including secondary perils and risks), and has led to model refinements and enhancements in all aspects of Japan earthquake models and beyond. When it comes to risk, the hazard is only one part of the story, and much was learned from the vulnerability perspective of how buildings performed in the earthquake and tsunami.

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