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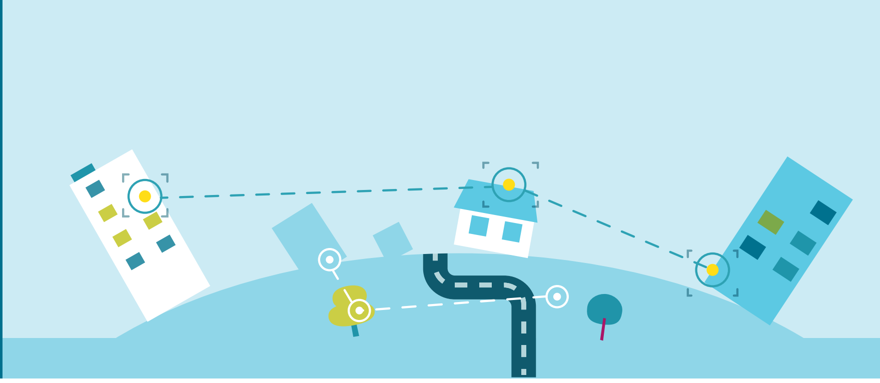


GUIDE TO EARTHQUAKES - PART III

Earthquake modelling for the (re)insurance Industry

Overview

Following on from SCOR's Guide to Earthquakes Part I and II, this third issue will focus on developing an understanding of the key inputs, strengths and limitations of existing earthquake models used by the industry today.

We also look ahead at what the future will deliver in terms of research, data, and models that will enable the industry to write earthquake risk with more confidence.

An event set framework to represent the risk

Catastrophe events are an identified trigger that could cause a company with poor underwriting performance, weak internal controls or failed processes to become insolvent (PACICC, 2013[1]).

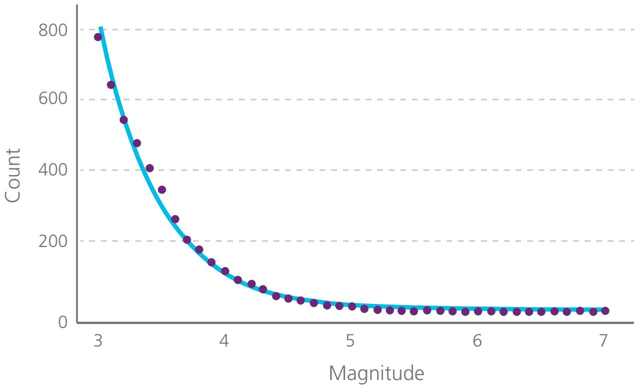
There are several historical examples where a natural disaster has caused insurers to fail. After the 1906 San Francisco earthquake, 12 insurance companies were declared insolvent, 8 after Hurricane Andrew in 1992 (7 domestic and 1 foreign), and 2 insurance companies went bankrupt after the 2011 Christchurch earthquake (PACICC, 2013).

MANY INSURERS HAVE DEVELOPED EFFECTIVE TECHNIQUES TO MANAGE THE SOLVENCY RISK OF NATURAL DISASTERS UTILIZING THE BENEFITS OF PROBABILISTIC MODELS.

Probabilistic seismic risk analysis has also greatly enhanced the insurability of natural catastrophe risks, with the World Bank utilizing this approach to initiate the Turkish Catastrophe Insurance Pool (TCIP) and the Caribbean Catastrophe Risk Insurance Facility (CCRIF) as just two examples.

Earthquake catastrophe models are based on the physical modelling of different types of earthquakes, as described in Part I and II of this guide, and calculating the damage that will result for a wide range of building types, sizes and vintages.

Figure 1: Illustration of the Gutenberg-Richter law



Source: Open Mind

The scale of the loss depends on the exposure value and building vulnerability as well as the probability of the earthquake itself.

Event based probabilistic models combine a source catalogue of thousands of possible events, each with a probability of occurrence and magnitude, with ground motion models and vulnerability functions to produce assessments of risk that are sensitive to given locations or portfolios of insured properties. The calculations result in the loss exceedance probability (EP) curve. The probability of an earthquake at any given location is estimated as a function of its magnitude. The Gutenberg–Richter law expresses the relationship between magnitude and total number of earthquakes for any given region and time period, as illustrated in Figure 1.

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1 - PACICC. 2013. Why insurers fail: natural disasters and catastrophes. Property and Casualty Insurance Compensation Corporation. Toronto, Canada.

Therefore, for every 1,000 magnitude 3 earthquakes that hits a region, there are 100 magnitude 4 quakes, 10 magnitude 5 quakes, one magnitude 6 earthquake and so forth. Because fault systems are finite in size, Gutenberg-Richter scaling cannot continue to arbitrarily large magnitudes at the upper end. On the previous page, at some cut-off magnitude, the event frequency must drop towards zero more rapidly than the exponential increase in magnitude. This maximum magnitude, which depends on the geometry and tectonics of the fault system, can be difficult to estimate precisely, as illustrated by the 2011 Tōhoku event, described previously in Part II of this guide.

The next step in the process is to calculate the ground shaking at every point on a grid that covers the impacted region for each event within the stochastic event catalogue. The ground shaking at any point is a result of multiple factors, such as the magnitude of the quake, distance from the fault rupture, the subsurface geology and an additional influence of the soil type at that location, known as soil amplification.

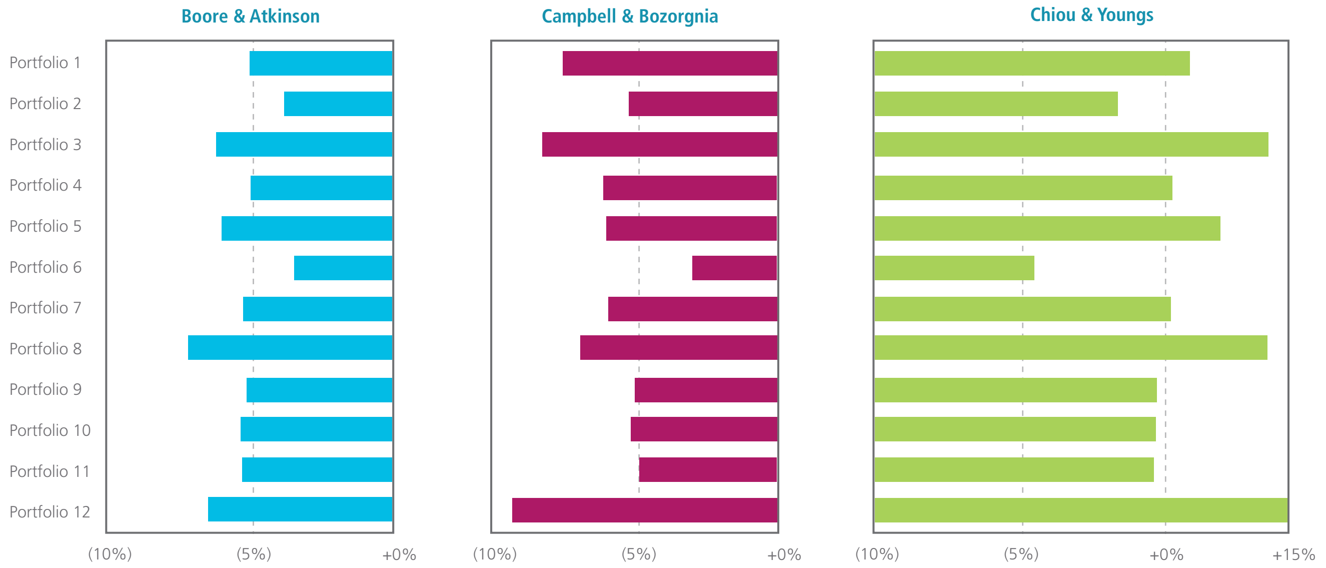
Attenuation relationships are used to calculate the decrease in ground motion with distance from the earthquake source, depending on the earthquake magnitude, the sub-surface geology and soil type. Attenuation relationships have multiple parameters, are developed from statistical analyses of observations obtained in similar geomorphic regions, and are region-specific.

The relationships for areas with the most observations will be the most reliable. Yet even in the U.S. which has a very rich dataset of historical earthquakes to draw upon, different attenuation relationships have been derived from the same data, reflecting the gaps that still exist in the data and the uncertainties that remain.

The Next Generation Attenuation (NGA) project was a collaborative research programme ending in 2008 with the objective of developing updated ground-motion attenuation relationships for the western U.S. and other worldwide active shallow tectonic regions, based on the large amount of new data that was gathered from earthquakes from the previous 10 years. Five sets of updated attenuation relationships were developed by teams working independently.

The individual teams all had previous experience in the development of attenuation relationships, all had access to the same comprehensive, updated ground motion database, and were free to identify portions of the database to either include or exclude from the development process. Yet, each of the attenuation relationships produce different results, as shown in the example of three of the relationships in Figure 2, demonstrating the uncertainty that exists even where data is available. The relationships were equally weighted in the development of the seismic hazard maps, as it is not possible to say that one is more accurate than another.

Figure 2: Percentage change in modelled portfolio losses with three different ground motion attenuation relationships: which either increase loss results (Chiou & Youngs) or decrease to different degrees (Boore & Atkinson/Campbell & Bozorgnia)



Source: RMS

Accounting for soil effects, lessons from Mexico City 1985

The 1985 Mexico earthquake dramatically illustrated a particular phenomenon which is now well understood: namely that it is possible for ground motions to be higher at greater distances from the source of an earthquake as a consequence local site effects.

Aztec art depicts a city built on a small island in the middle of a large lake. This lake later dried up, allowing the city to develop and grow: becoming Mexico City. In 1985 an Mw 8 earthquake occurred 350 kilometres away from Mexico City and seismic waves shook the city 100 seconds later.

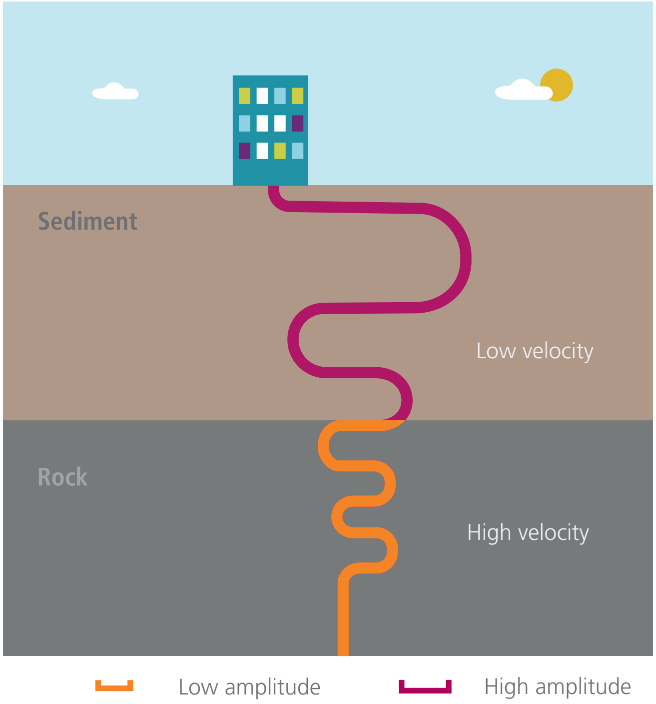
> RECORDINGS SHOW THAT THE GROUND MOTION AT THE CITY PERIPHERY, BUILT ON VOLCANIC ROCKS, WAS A TENTH OF THAT IN THE CITY CENTRE, BUILT ON CLAY SEDIMENTS FROM THE ANCIENT LAKE.

Seismic waves with a frequency of 0.5 Hz were amplified so much in the city centre that 20-storey high buildings vibrated in phase with the ground motion, before collapsing after 10 or 20 seconds. Such amplifications occur in sedimentary basins which trap and amplify ground motions between the hard rock below and the sedimentary soil, as illustrated by Figure 3.

Other cities resting on top of sedimentary basins include Tokyo, Seattle, Los Angeles, parts of the San Francisco Bay area, and Kathmandu. Most catastrophe models include the effect of soil amplification in their estimation of ground motion values: though it can be a source of significant difference between model outputs.

The accuracy and resolution of soil data used in the development of an earthquake model can be another key reason for differences between model output and results. For example, two different earthquake models may use the same historical catalogue of earthquakes, seismic hazard maps, and attenuation functions such as from the USGS (United States Geological Survey), but use different resolution databases of soil type.

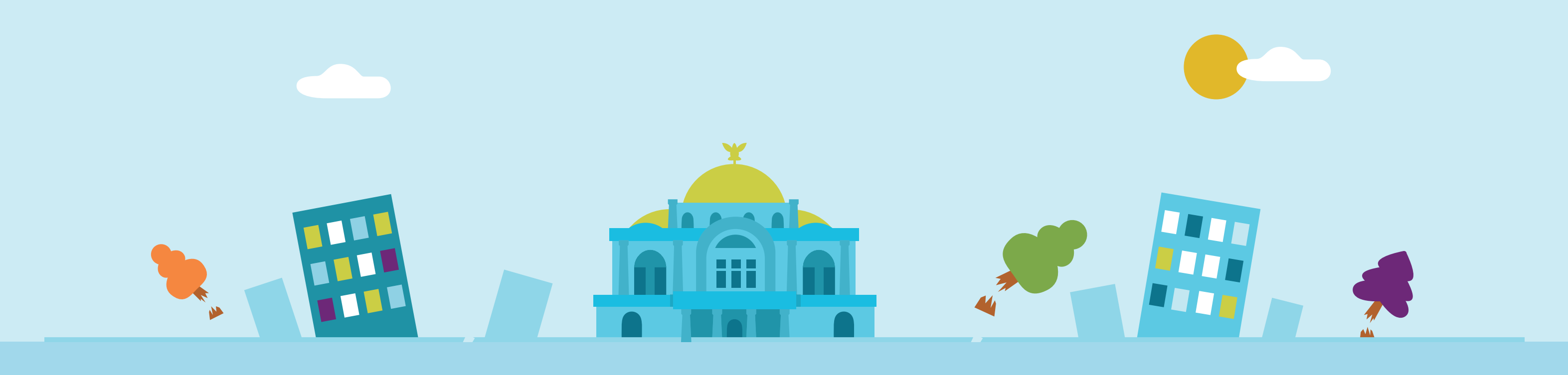
Figure 3: Illustration of the increase in wave amplitude which occurs with the transition from higher velocity rock to lower velocity sediment



Source: Geoscience Australia

In addition, whilst the horizontal resolution may be relatively high, information about subsurface soil layers may be lacking. For example in the 2011 Christchurch earthquake, the liquefiable sand lenses hidden in the subsurface were not identified in available soil maps. **This type of uncertainty can impact location level loss calculations significantly,** and have an impact across a whole portfolio.

Vulnerability functions are applied to calculate the damage ratio for a wide range of building types and occupancies for any given hazard level, which take into account factors such as the age of the building, its height, its construction type, and the presence of any building-specific damage modification factors. For example, whether a masonry building is reinforced or not is a key determinant of its response in an earthquake: the prevalence of unreinforced masonry buildings globally being of great concern given their high propensity to collapse in earthquakes.



Another key concept in earthquake engineering and vulnerability is whether the building is "ductile" or not: highly ductile buildings retain elasticity and flexibility during shaking, whereas non-ductile buildings are more brittle and vulnerable to collapse. Buildings with a "soft storey" are also highly prone to failure: soft storey meaning that there are large open spaces or openings on the ground floor, such as full height glass panels (e.g. shop fronts) or parking lots with openings to the street. The decreased structural integrity of these buildings makes them vulnerable to collapse in earthquakes.

The frequency of ground motion vibrations and the characteristics of the building interplay so that tall buildings will in effect experience a different intensity than short buildings from the same earthquake. Resonance of a building occurs when the natural period of the building matches that of the incoming seismic waves. Short, stiff structures are most affected by high frequency shaking. Conversely, tall buildings are more affected by **low-frequency long-period seismic waves.**

Did you know?

Spectral acceleration (Sa) is in essence a measure of the maximum acceleration that the building experiences, and depends on the height of the building.

Modelling spectral acceleration will capture this interaction and provide a more accurate differentiator of building damage than modelling intensity or peak ground acceleration, if combined with detailed information about the building characteristics, particularly height and construction material.

Given the low frequency of damaging earthquakes there is a relative lack of claims data for calibrating vulnerability functions compared to, for example, hurricanes striking the U.S. Gulf coast and Florida.

Thus, to work around this, engineering studies both pre- and post-disaster are extensively utilised in developing vulnerability functions. There are many dedicated research centres focused on understanding the structural performance of buildings in response to earthquakes.

In particular there are more than 100 so called "shake tables" around the world: consisting of a movable platform upon which a scale model or even full-sized building is constructed, and conditions representative of ground motions can be simulated, as illustrated in Figure 4. For some good examples of shake-tables in action, see **The Pacific Earthquake Engineering Research Center** (PEER) at the University of California, Berkeley, the China Academy of Building Research, Beijing or Japan's NIED 'E-Defence' Laboratory in Hyogo.

Another consideration in understanding and modelling building performance to earthquakes is the seismic benefit that results from design codes for wind loading, as is often cited to be the case for Hong Kong for example. Tall buildings designed and built to wind loading regulations have a greater inherent capacity to resist ground shaking of all frequencies.

Figure 4: Illustration of a model-scale shake table

Source: University of Nevada, Las Vegas

Remaining uncertainties and model limitations

As catastrophe models have become more integrated into the business process, reliance on them has increased, yet we must remain cognizant of the limitations of modelling and uncertainties, so that we can offer appropriate risk transfer solutions which do not leave the risk bearer exposed.

Earthquake catastrophe models today offer a view on hazard excluding foreshocks, aftershocks and event swarms. This is a direct consequence of the methodology used in earthquake hazard studies which assumes that events are independent.

This translates business-wise into difficulties in pricing programmes such as annual aggregate reinsurance or reinstatements where the frequency of events within a specified time period is important, or per-event XOL since the probability of a first event in the next treaty year is significantly raised.

The Emilia 2012 sequence in Italy, Christchurch 2011 sequence in New Zealand and New Madrid 1810 – 1811 sequence in the U.S. still have no analogue in any modelling software at the time of writing, though future model releases should start to address this.

There are some specific complexities in modelling multiple events that have led to this situation. Firstly is the unpredictability of aftershocks and foreshocks, and secondly, lack of known correlations.

> SCIENTIFICALLY WE KNOW THAT AFTERSHOCKS FOLLOW EARTHQUAKES, BUT THE SCIENCE BEHIND KNOWING PRECISELY WHERE AND WHEN THEY WILL OCCUR IS FAR FROM CERTAIN.

Thus, aftershocks need to be modelled stochastically: which is becoming more feasible as increases in compute power enable **calculations of the multitude of possible combinations**, yet still deliver analysis results in time scales of practical use to the business. Another issue is modelling damage from aftershocks.

The damage sustained by a region from a main shock means that the weakest structures will have already collapsed, and the incremental damage is not as high as would be expected for that magnitude earthquake alone.

Yet on the other hand, buildings that survived the first earthquake may have been weakened, and thus more vulnerable to the aftershock, but this is typically a smaller factor than the first.

Some outstanding questions remain on the mechanisms of seismicity itself. The series of great earthquakes since 2004 has raised questions and prompted active research into whether such large earthquakes can trigger others far away on apparently completely separate fault systems, though no physical explanation or statistical tests can find a link between these recent great events (Shearer, 2011[2] ; SCOR, 2013[3]). Research into this question is ongoing in the scientific community.

Many available earthquake models do account for time dependence on individual major faults, such as on the San Andreas and the North Anatolian fault, as described in Part II of this guide. The impact of time-dependence assumptions versus a time-independent view on losses can be tested in many models, as a way of testing the variance on loss results for any particular portfolio, and the user must remember that the time dependence estimates also come with associated uncertainty, often unquantified.

Most models available for use in the industry incorporate the impact of locally aggravating factors such as soft soil conditions and liquefaction, as illustrated in figure 5 (see overleaf). However, during the Christchurch 2011 event some areas, particularly the eastern suburbs, were subject to a degree of liquefaction beyond previous experience, due to the specific combination of the soil type (including the presence of sand lenses at depth), the saturation (degree of wetness) of the soil, and the frequency of the ground motions.This "ultra" liquefaction was not adequately modelled, and there are other parts of the world that could be similarly subject to this level of aggravated liquefaction.

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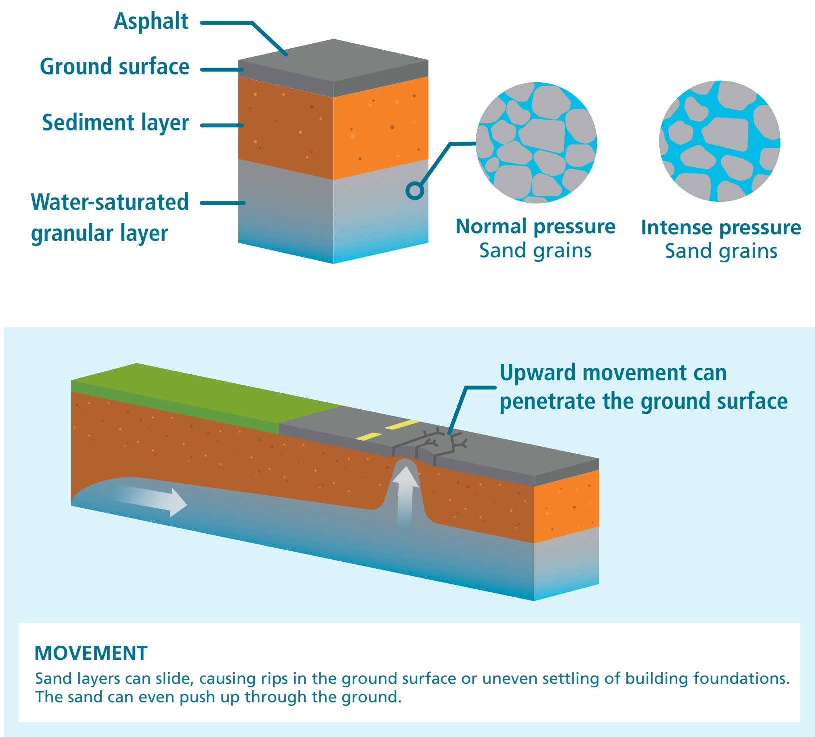
[2] - Shearer P. M., Stark P. B. 2011. Global risk of big earthquakes has not recently increased. PNAS 109 (3): 717–721.
[3] - SCOR. 2013. Are great earthquakes clustered? SCOR Papers #23.

Figure 5: Illustration of soil liquefaction and its consequences



MOVEMENT

Sand layers can slide, causing rips in the ground surface or uneven settling of building foundations. The sand can even push up through the ground.

- Liquefaction is a phenomenon in which **water saturated sandy layers of earth act like liquids** due to the pressure created by earthquakes.
- The force from an earthquake increases the pressure of water in these saturated sandy layers of earth, which in turn **reduces the friction between the sand grains.**
- Reduced friction allows the sand grains to move more freely, hence under extreme pressure this **sand layer behaves like a liquid.**
- The resulting movement and sliding of the sand layers can cause **rips in the ground surface and de-stable building foundations.**

Source: California Watch

Another source of model gap revealed over the past 10+ years in events such as 2004 Sumatra-Andaman Islands, 2010 Maule and 2011 Tōhoku earthquakes, has been that of far-field tsunami modelling. Some models are now available, and are steadily being rolled out globally, but model users should be aware of which regions are prone to major tsunami, and whether their catastrophe model suite adequately captures this risk or not.

The influence of earthquake duration is not explicitly taken into account in vulnerability modelling in today's catastrophe models. Ground shaking can last 3+ minutes in major megathrust subduction earthquakes; but will typically be less than 1 minute in most M6-7 events. Buildings need enhanced ability to deform in a ductile manner over a longer timeframe in longer duration events. However, the modelling of event duration and vulnerability response at such a detailed level, across 10,000s of simulated events is beyond the ability of today's catastrophe models and platforms.

Adaptation of vulnerability functions to local building practices and the degree to which building codes are in place, and more importantly if they are effectively enforced, is important: but the latter is difficult to know.

Measures of wealth and corruption, such as **the Corruption Perceptions Index from Transparency International**, are used by Professor Roger Bilham to identify countries which have above or below expected levels of building standards than would be expected based on their wealth alone (Bilham & Ambraseys 2011[4]). It is also worth noting that building codes are designed to protect against loss of life, not to prevent all building damage.

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4 - Bilham R & Ambraseys N. 2011. Corruption kills. Nature 469: 153–155.

Therefore, buildings may still be standing after an earthquake, and have performed according to the design code, but can still be written off from an insurance perspective. An additional issue is that many properties were **constructed before the existence of building codes**, although in some countries, substantial investments have been made to retrofit properties with structural enhancements to comply with more recent building code standards. For example in Istanbul, the awareness of the high probability of the region being impacted by an earthquake of at least magnitude 7 has led to retrofitting or reconstruction of 1,086 public buildings via a disaster preparedness program supported by the World Bank Group and the Global Facility for Disaster Reduction and Recovery. This takes time, for example it is expected that it will take decades for Singapore's building stock to fully reflect the enhanced building codes introduced in 2013. These were formulated in recognition of the risk from far-field earthquakes from sources such as the Sunda Trench and Sumatran Fault Zone, **combined with rapidly growing high insured property values concentrated in a very small area**, much of which is medium to high rise and on soft soils and infill.

Knowing the age of the property being insured is therefore an important determinant of potential loss, as is knowing if older buildings have undergone any seismic retrofitting to more recent building design codes. This can be accounted for in many models through secondary modifiers which will modify the vulnerability accordingly.

When using the "year built" building characteristic in catastrophe models, one must be aware of time lags due to the length of many building projects. For example, is the year built the year in which planning was approved, or in which the building was completed? The completion date may be the year in which the building code was introduced, but the building could have been designed and approved in a previous year, when the building code was not in place. Some earthquake models build in a 1-year time lag in the application of building codes in order to account for this, at least partially.

Finally, contingent business interruption and aggravating factors such as time-of-day of occurrence which determines where people are and thus how many casualties there may be for workers-compensation modelling, or a strong wind propelling and strengthening a subsequent fire, are not included in the probabilistic models currently in use.

Globalized supply chains create new sources of loss that also lay outside of today's models: Toyota stated they lost US$1.2 billion in product revenue from the 2011 Tōhoku earthquake and tsunami due to parts shortages from affected suppliers that caused 150,000 fewer Toyota automobiles to be manufactured in the U.S., and reductions in production of 70% in India and 50% in China.

Outlook for earthquake risk modelling and management

Although a large proportion of the damage sustained from earthquakes globally has to date been uninsured, new initiatives are underway to extend insurance coverage for earthquakes in many parts of the world (Lloyd's Global Underinsurance Report, 2012[5]).

Many international organisations, such as the United Nations, increasingly recognise the benefits of catastrophe insurance to provide incentives for ex-ante risk mitigation via price signals, such as reduced deductibles or improved rates for earthquake-resistant structures, together with quick access to ex-post funds for repairs, reconstruction and recovery, relieving the burden on tax payers, governments and the international donor community.

The scientific and engineering understanding of earthquake risk continues to evolve: after damaging earthquake events, earthquake engineering collaborations and organisations such as the Earthquake Engineering Research Institute (EERI) in the U.S. and the Earthquake Engineering Field Investigation Team (EEFIT) in Europe conduct field investigations and produce reports for the local and international engineering community on the performance of civil engineering and building structures under seismic loading. These investigation teams typically comprise of both academic and industry based engineers and earthquake scientists, and results often feed into catastrophe model enhancements and updates, as well as into design codes and broader societal responses.

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5 - Lloyd's Global Underinsurance Report. October 2012. Centre for Economics and Business Research Ltd. London.

Looking forwards, increased computing power is now enabling far-field tsunami modelling coupled with earthquake models, with the first models released in 2013 and coverage steadily growing over the world. Modelling of earthquake clustering is on also on the horizon with the first models expected in 2016, and additionally the outcomes of new studies will incorporate the possibility of M9+ earthquakes on faults previously thought to be unable to produce events of such magnitude.

The Global Earthquake Model (GEM), initiated in 2006, is delivering an enhanced and consistent understanding of global earthquake risk, together with resources and applications to make this information widely accessible to facilitate decision making for risk management and mitigation. GEM is a collaboration between multiple public and private partners and stakeholders around the world. Their OpenQuake platform launched in January 2015 and can be downloaded from their website, along with a global database of historical earthquakes and other data and resources on seismic hazard and risk.

Another recent development is the **OASIS loss modelling framework**, a non-profit open-source catastrophe modelling platform and associated set of standards, funded by the re/insurance industry. A multitude of organisations, modellers, academics, public bodies and others will be able to deliver and share risk data, models and information via the OASIS platform with the re/insurance industry and each other, without the costs typically involved in developing a delivery platform. The first version of the platform was delivered in 2015, with many new models being delivered to the industry via this platform in 2016.

Summary

These latest modelling initiatives together with a thorough understanding of the issues discussed in this three-part guide will enable earthquake risk to be transferred and written with greater understanding by the re/insurance industry: facilitating the goal of increased industry coverage of global disaster risk.

The emergence of new public-private partnerships following global agreements in 2015 such as the Sendai Framework for Disaster Risk Reduction, the Sustainable Development Goals and COP21 will enable the knowledge and expertise of the catastrophe re/insurance industry to be shared more broadly with governments and communities as the basis for a more holistic and effective approach to disaster risk management in the coming years and decades. **Risk modelling and risk assessment will continue to lie at the core of this future.**

PAUL NUNN
Head of Risk Modelling and
Global Natural Hazards
SCOR Global P&C

pnunn@scor.com

For more information, please contact our team

Dr. Kirsten MITCHELL-WALLACE, kmitchell-wallace@scor.com
George COOPER, gcooper@scor.com
Dr. Ismaël RIEDEL, iriedel@scor.com

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SCOR Global P&C
5, avenue Kléber
75795 Paris Cedex 16
France
scorglobalpc@scor.com

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