Mitigating, managing and quantifying earthquake risks

September 2023

Earthquakes can cause damage far from the faultline or epicentre depending on the geology, soil type and the vulnerability of the building or location.

In our recent webinar on Thursday 11 May 2023, we discussed how and where earthquakes happen, their impact on property and business and how risk consultancy modeling and analysis can help businesses to measure, mitigate and manage their risks.

We also explored:

- What causes earthquakes?
- Why the damage varies so widely from location to location.
- How we quantify risks and probable losses.
- Alternative risk transfer solutions for difficult to place earthquake risks.
- Real world risk consultancy and claims examples.
- Current research into earthquake-related risk topics.

WTW speakers

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What are earthquakes?

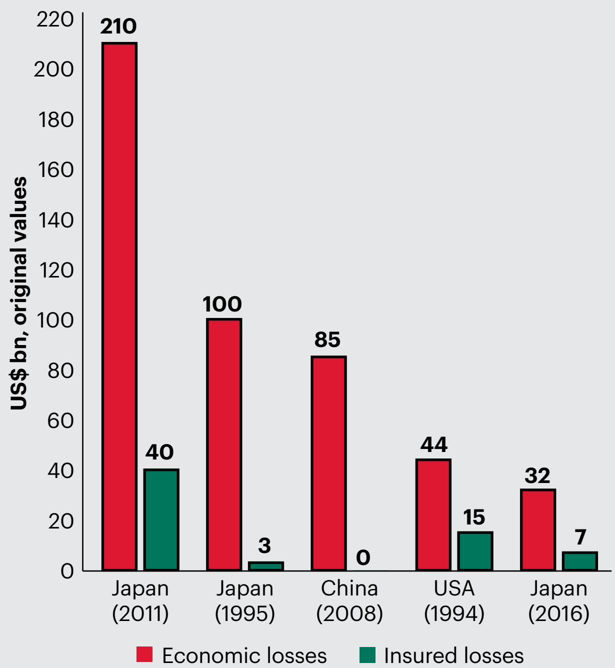
An earthquake is the shaking and vibration of the ground due to energy released when two tectonic plates suddenly slip past each other. On average there are around 15 major earthquakes every year around the world. It's impossible to predict when or where an earthquake will happen.

As well as the damage caused directly by the tremor, quakes can trigger secondary catastrophes such as tsunamis, landslides and sinkholes. They can also lead to fires and explosions if gas or electrical lines are affected. All of which increase the risk to life and property and the scale of business losses.

There are two ways of measuring earthquakes:

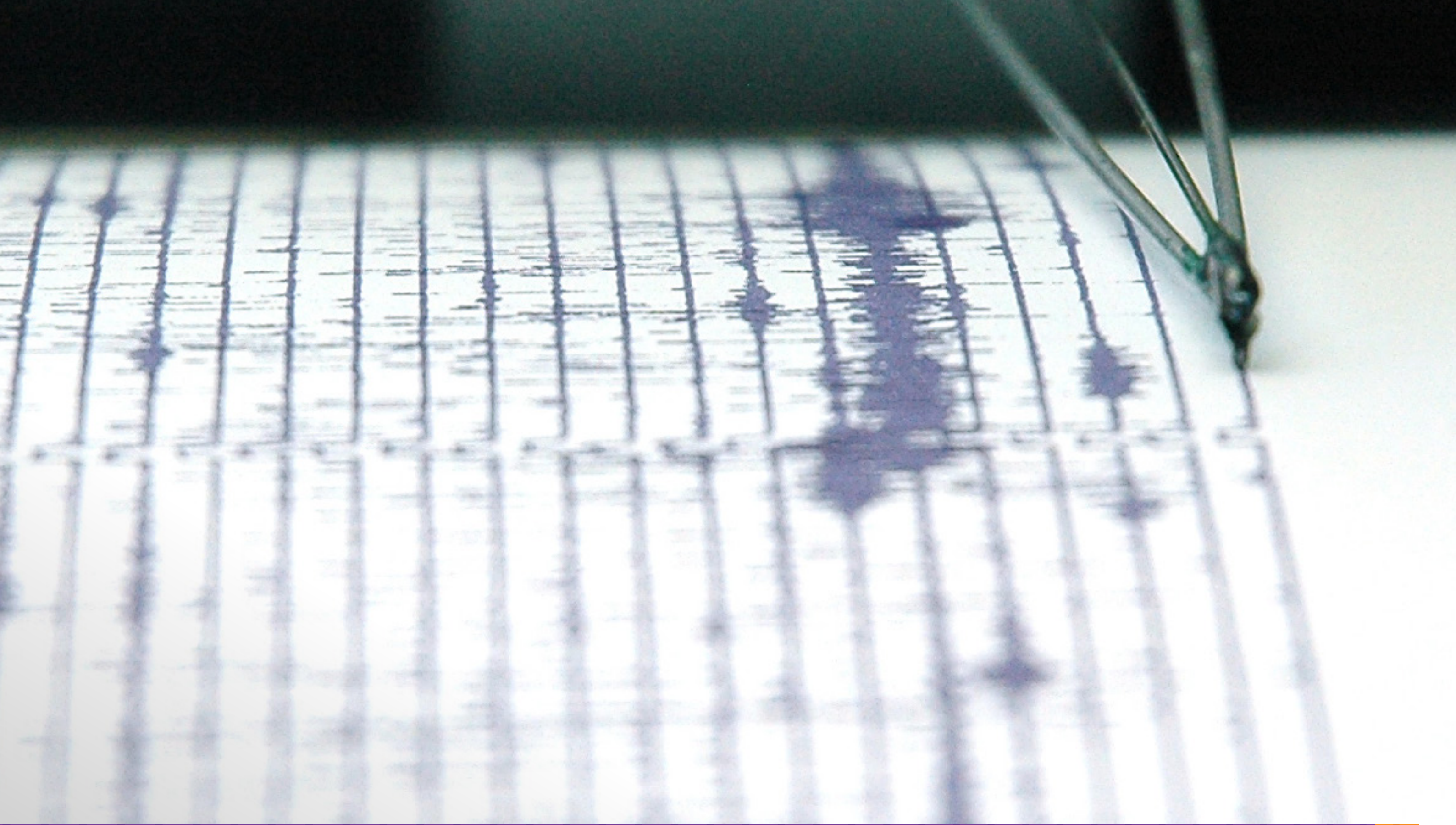
- **The magnitude e.g. Moment Magnitude (Mw)** measures the strength of the earthquake.
- **The Modified Mercalli Intensity (MMI)** measures the intensity of the shaking at particular locations and the likely impact of an earthquake based on geology and soil types.

Figure 1: **The 5 largest earthquakes 1980-2022 by economic losses**[1]



Source: Munich Re NatCatSERVICE

[1]https://www.munichre.com/en/risks/natural-disasters/earthquakes.html#:~:text=The%205%20largest%20earthquakes%201980%2D2022&text=The%202011%20Tohoku%20Earthquake%20off,caused%20the%20Fukushima%20nuclear%20disaster



How do earthquakes happen?

Earthquakes occur when two tectonic plates slip past each other. There are three main theories on the cause of plate tectonic motion:

- **Mantle convection currents:** super-heated parts of the earth's core cause the semi-molten mantle above them to rise by convection, pulling on the tectonic plates above.
- **Ridge push:** newer plates are less dense and float higher than older plates above the earth's mantle, which pushes older plates away.
- **Slab pull:** denser older plates sink into the earth's mantle, dragging the newer plates with them.

Where do earthquakes happen?

Earthquakes can happen almost anywhere depending on how the plates move. But the largest and most destructive are at the plate boundaries where there is most friction. There are three types of plate boundary that can create quakes, as shown in *Figure 2* below.

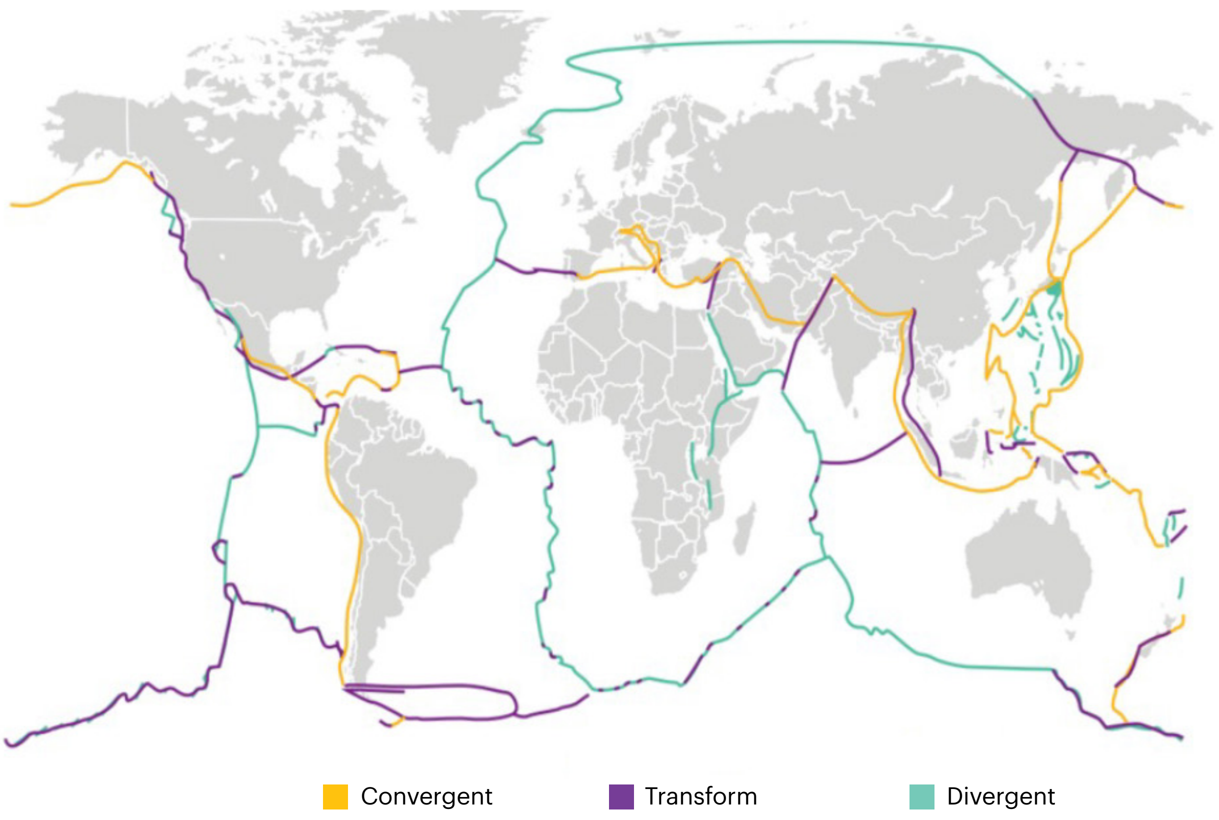
Figure 2: **Three different types of plate boundary**

Boundary type	Cause	Strength	Found in...
Convergent	Plates collide and push into or under/above each other	**Strongest** can exceed Mw 9	Chile, southern Europe, Asia-Pacific
Transform	Plates slide past each other in the same or different directions	**Strong** up to Mw 8.5	California, New Zealand, South East Asia
Divergent	Plates move away from each other	**Least strong** Typically less than Mw 8	Iceland, East Africa

Where do earthquakes occur?

Figure 3: **A map of tectonic plate boundaries**

Earthquakes can occur anywhere in the world but areas at the highest risk are usually found along **plate boundaries**.	Coastal regions near to fault lines also experience **tsunami** risk.	Convergent **plate boundaries** produce the largest magnitude earthquakes.



Example:

Turkey-Syria earthquake 2023

One of the most devastating earthquakes in recent history struck south east Turkey and northern Syria in February 2023, causing severe damage across an area the size of Germany and killing around 60,000 people.

One of the biggest factors in the scale of the devastation was the type of construction as some buildings collapsed completely while others stayed standing.

Although building codes had been upgraded in recent years, many new buildings did not follow the codes and older buildings were not retrofitted to comply with them.

The tragedy highlights the importance of building construction, structure and materials in assessing earthquake risks and mitigating against them.

Magnitude:
Mw 7.8

Damage area:
350,000 km²

Population affected:
14 million

Losses *($5 billion insured):*
$25 billion

How can we quantify a client's risk?

How can businesses with sites in or near earthquake zones tell how much damage will be caused if a quake happens?

Although the greatest devastation is likely to happen at the epicentre of an earthquake, the risk of major damage can be distributed across a wide area and vary depending on the local geology and soil type.

It's critical for clients in or close to earthquake risk areas to understand the level of risk in their specific location and the vulnerability of their buildings and equipment to the likely impact.

Historical analysis

Traditional methods of assessing earthquake risk include a historical analysis of recorded quakes. By looking at the intensity of earlier quakes across a geography, you can build a picture of the potential future risk in different locations and produce hazard maps, showing the higher and lower risk areas. But historical analysis is limited. Seismic records only go back around 100 years. There may have been much larger events before then, which will affect the probability of future earthquakes.

Catastrophe modeling

Catastrophe modeling tools can take account of much longer periods using a wider range of data. They can produce a more comprehensive view of earthquake risk and calculate the probable financial losses in a range of possible earthquake scenarios, including the likelihood of a company's loss threshold being exceeded.

Models depend on the quality of information used for analysis.

As discussed above, earthquake risk can vary widely depending on factors such as the type of earthquake, the local geology, soil type and the vulnerability of buildings. To produce accurate models of probability requires detailed geolocation information and construction data such as the building type, occupancy, age, floor area and number of storeys.

An example of a catastrophe model output is shown below. It includes:

- Ground up loss: the total likely financial loss caused by the event
- Gross loss: once insurance conditions, such as deductibles and limits, are applied
- Average annual loss: this can help calculate the annual insurance premium needed
- Return period: the likely frequency of a loss reoccurring over an extended period
- Probable maximum loss (PML) — the likely loss if worst case earthquake happens
- Co-efficient of variation — shows the level of uncertainty about the model results.

In this example, we calculated that an earthquake with a PML of $52.8 million (4th column) was likely to reoccur once in 250 years (2nd column), equating to a probability of 0.4% (1st column) in any given year.

Figure 4: **A typical modeled loss calculation**

Modeled Exposure
The Total Insured Values (Buildings, Contents and Business Interruption combined) modeled for the peril and region of interest.

Ground Up Loss
Estimated losses **BEFORE** insurance conditions have been applied.
Also known as 'True Loss'.

Gross Loss
Estimated losses **AFTER** insurance conditions have been applied.
Also known as 'Insurer loss'.

Return Period
An estimate of the frequency (in years) that the portfolio will sustain a loss of a given size or greater.

Exceedence Probability
The percentage probability of the portfolio experiencing the estimated loss values or greater.

Earthquake			
		Ground up	**Gross Loss**
Modeled Exposure		**9,861,729,184**	**9,861,729,184**
0.01%	10,000	679,493,455	501,489,172
0.40%	**250**	**57,790,448**	**52,866,064**
1.00%	100	30,899,825	24,945,023
2.00%	50	17,215,724	11,515,630
20.00%	5	257,272	0
	Average Annual Loss	1,690,996	1,113,387
	Standard Deviation	17,733,244	10,874,524
	Coefficient of Variation	10.49	9.77

Probable Maximum Loss (PML)
The worst case expected after taking into account relevant mitigating factors that may prevent a maximum possible loss (MPL), such as shutters on windows or sprinkler systems.

Average Annual Loss (AAL)
Also known as the pure or technical premium, it provides an estimate of premium required to protect against all catastrophic losses. The higher the value, the higher the exposure of the portfolio.

Standard Deviation
Gives a view of the volatility in the average annual losses. Provides a measure of how close the actual loss for a given year is likely to be to the average annual loss (AAL). The higher the difference between this value and the AAL, the greater the margins of uncertainty.

Coefficient of Variation
The standard deviation divided by the average annual loss (AAL). It can be used to compare other perils or portfolios.

Claims case study:

Vehicle distributor in Texas, Japan tsunami

Contingent business interruption (CBI)

When the earthquake and subsequent tsunami hit Japan in 2011, it severely reduced manufacturing capacity among some Japanese car component makers. This, in turn, reduced the supply of new vehicles for our client which distributed Japanese cars in the U.S.

WTW helped them claim under contingent business interruption cover, which reimburses lost profits and expenses resulting from an interruption of business at the premises of a supplier or customer. After detailed negotiations, insurers agreed to pay the full claim of $15 million — the client's total CBI sub-limit.

This demonstrates how WTW claims advocates, working with London market insurers, can help clients to make successful claims and recover from the financial impact of an earthquake, even when their business does not suffer physical damage.

Strategic risk consultancy for earthquakes

As described above, the damage caused by earthquakes can be very different between two locations in the same geographic area, or between two quakes of similar magnitude. This can make it difficult for organizations to decide on appropriate mitigation or how much insurance to buy.

To help them make these decisions, WTW offers a comprehensive risk consultancy service, including catastrophe modeling, in-depth hazard analysis, and risk engineering. Armed with the right information clients can see their mitigation, risk management and risk transfer options more clearly.

Example:

Modeling and risk mitigation analysis for real estate firm, California

A North American real estate investment company with a portfolio of properties in an earthquake-prone area wanted an assessment of:

- Earthquake risks for its main assets
- Which risk mitigation measures would have the greatest impact in reducing its vulnerability to a future earthquake

Quantitative risk modeling analysis

We used industry leading catastrophe models to run 10,000+ simulations of plausible events that could occur in the area to provide an estimate of expected losses.

Model sensitivity analysis

A model sensitivity analysis examined the vulnerability of individual assets and identified the risk mitigation measures that would have most impact in reducing earthquake damage. This was based on physical characteristics such as construction type, year of construction, and whether equipment was braced against earthquake shaking.

Through this process, we found that 60% of the average annual losses predicted for the whole portfolio came from just three properties. In all these locations, the buildings were mainly made of unreinforced masonry, which is particularly vulnerable to sheer forces caused by earthquake shaking. Therefore retrofitting the masonry on these buildings would have the greatest impact in reducing overall portfolio loss.

Cost-benefit analysis

We estimated the cost of retrofitting the masonry at $10 million. The likely reduction in losses in a 1 in 500 year loss scenario if the retrofitting was done, was around $150 million, far outweighing the cost. We also provided information on the best retrofitting methods.

Recommendations for next steps

A deeper dive earthquake risk engineering assessment for a more accurate quantification of the cost and benefit of proposed risk mitigation measures.

Example:

Risk engineering for a major port in South America

Having extended the port and invested in new assets, the owners wanted to understand their probable maximum loss from an earthquake and tsunami, assess the vulnerability of their assets and also provide mitigation solutions that might help them manage their risks.

Detailed hazard assessment and site survey

We carried out a detailed local tsunami and earthquake hazard assessment, including site-specific hazard quantification looking at ground shaking and tsunami inundation.

We did a survey of the site to find out how vulnerable buildings, equipment and stock would be to an earthquake. We spoke to engineering, operations, and finance staff to work out the potential impact on day to day operations and the potential business interruption that could occur.

We also reviewed design specifications and drawings against minimum design standards required by local government.

Physical vulnerability assessment

From our on-site survey we found that one of the piers was in bad condition. Some equipment, including important assets, were unanchored with no lateral bracing.

The structure of the cranes was designed for a peak ground acceleration (PGA) of 0.2, whereas we predicted PGA could reach 0.6. From this, we advised that cranes were likely to suffer structural damage in an earthquake. We noted that some cranes had seismic isolation devices to protect them from the worst impacts of an earthquake, but this would not protect them from damage in a tsunami.

As a result of our detailed assessment and modeling, we found there was a high risk of liquefaction locally, which could cause subduction of the land around the port, further increasing the potential scale of tsunami inundation and damage.

Probable maximum losses

Using all of this information, we modeled the probable maximum loss due to the combined impact of an earthquake and tsunami, with a 475 year return period. Our analysis also included an estimate of the business interruption costs and the increased cost of working, for example if dredging was needed to return the port to normal operation.

Mitigation strategies

Construction: we recommended reinforcing the construction of piers and making sure that all essential electrical power installations are adequately tied down at their bases to avoid sliding or overturning as a result of strong ground shaking during a major earthquake.

Business Interruption: we identified possible loss of cranes as the main business interruption risk, with a 6-month lead time for getting replacements. We advised having pre-agreed arrangements with local repair and spare parts contractors to help reduce the potential downtime following a catastrophic event such as a major earthquake and tsunami. We also recommended having evacuation places for expensive equipment, such as cranes, when tsunami warnings are issued.

Alternative Risk Transfer

Alternative Risk Transfer provides alternative ways to cover risks that may be difficult or expensive to place through traditional insurance markets.

It includes:

- Parametric solutions for specific risks that might not be insurable through regular policies.
- Alternative multi-year or multi-line structures designed around client needs.
- Captive solutions enabling companies to retain risk through a separate insurance company wholly owned by the insured.
- Access to Insured Link Securities and Cat Bonds through the capital markets, which can sometimes offer a better price than the insurance market.

Parametric solutions

Parametric solutions provide cover for specific perils, usually weather or natural catastrophe risks. They pay out when a particular event reaches a certain magnitude in a particular location according to a measurement or formula that is pre-agreed between the insurer and the client.

So, for example, a parametric policy might pay out a certain amount if an earthquake is measured by the authorities at Mw 7.5 or above in that is within a specified distance of an insured location.

Because claims are based on an agreed measurement, rather than an estimation of losses, they can be paid quickly, usually within 30 days.

Why are parametric solutions useful for earthquake risks?

Parametric solutions can cover earthquake risks that property insurance doesn't cover. For example, property policies might only cover business interruption if the insured property has been damaged. But a hotel in an earthquake zone could suffer a dramatic fall in guests even if it has not been damaged. For example, surrounding infrastructure might have been badly damaged. In this case, a parametric solution could be arranged to cover this non-damage business interruption.

They may also be an attractive alternative where property cover can't provide large enough limits or has large deductibles for natural catastrophe perils. In this way, parametric solutions can infill the deductible or provide extra cover on top of limits of a traditional property program.

Example:

Parametric earthquake solution for a public entity in the U.S.

This client had sites across a wide geographic area. They need to ensure immediate cash flow in the event of a large earthquake to meet potentially large requirement for resources and assistance.

The parametric solution provided that a payout would be triggered if peak ground acceleration (measured relative to gravitation acceleration, 'g') was above a certain level at specified locations. At 0.45g (strong shaking), the pay-out would be $5 million, at 0.6g it would be $10 million, at 0.75g (very strong shaking) $15 million, and at 1.15g (severe shaking) $20 million.

This would provide instant access to cash flow during critical earthquakes with payouts independently calculated using open-source data and a pre-agreed formula.

Cover was structured over a three-year term, which reduced the cost of premiums because the chance of having a large earthquake in each of the three years was very low.

Example:

Non-damage BI cover for a tourism company in New Zealand

The tourism company was concerned about the impact of an earthquake that might put international tourists off visiting New Zealand.

We designed a non-damage business interruption parametric solution based on an earthquake affecting the New Zealand's two main airports, which would cause disruption to air travel and cut off the supply of tourists.

It provided that if either airport was hit by an earthquake of magnitude 7 or above, the company would receive a $5 million payout.

To arrive at this calculation, we carried out research such as how earthquakes are measured and reported in New Zealand, analysis of vulnerabilities in the surrounding road network and comparison of previous catastrophic events and their impact on tourism numbers.

WTW Research Network

The WTW Research Network (WRN) supports our risk teams in bringing best practice science-based research and evidence into our: risk models, advice, thought-leadership, insights and events.

The team includes 12 specialists based in the UK, U.S. and Denmark, plus a wider network of more than 60 partners in science, academia, think tanks and the private sector.

One of the main themes of their research is how risks interact with each other — for example, how climate change impacts on a range of non-climate risks — and how to use this knowledge to increase resilience. The team also helps to quantify natural catastrophe risks and identify new and emerging risks and trends.

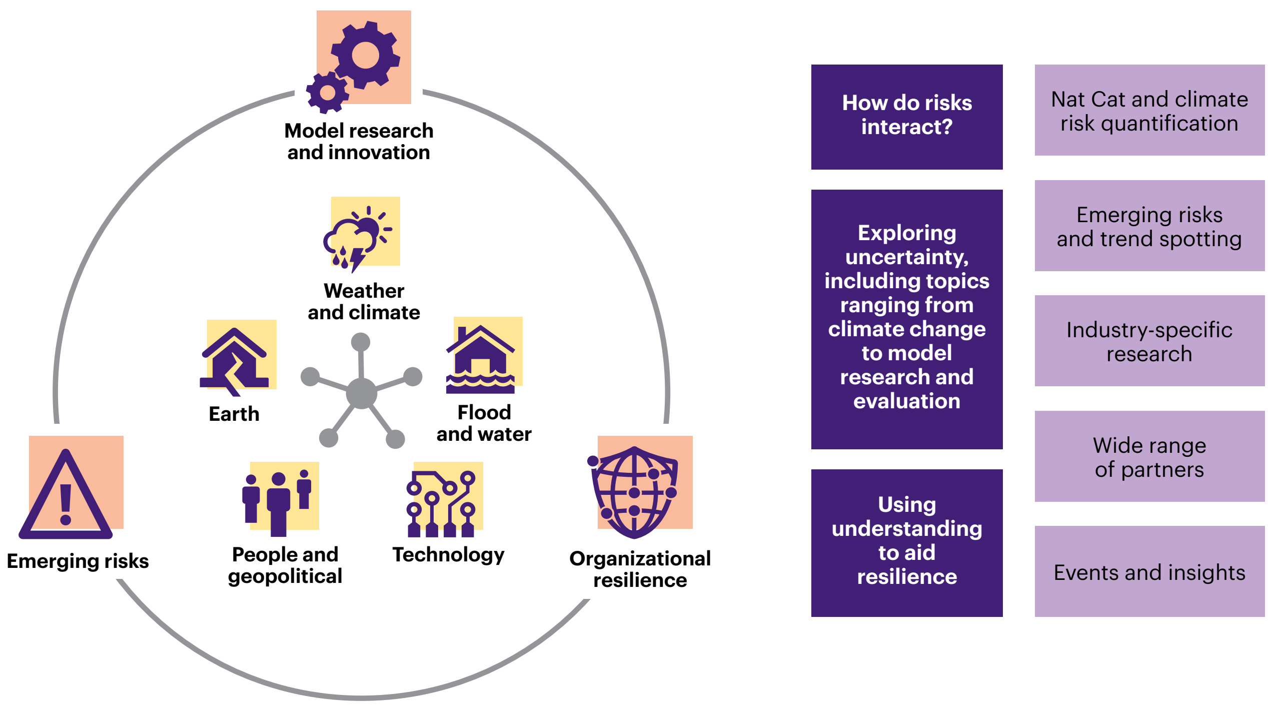
The network is grouped into hubs looking at different global risk areas. The **Earth Risks hub** looks at geological hazards including earthquakes, volcanic eruptions tsunamis and landslides, working with industrial partners including Temblor Inc. and the Global Earthquake Model Foundation (GEM), and academic institutions such as San Diego State University, the University of Oxford and D'Annunzio University.

Current earthquake research topics include:

- **Model evaluation** including how Probabilistic Seismic Hazard Assessment models predict probability, location and peak ground acceleration of future events from historic catalogs, stress and strain changes on faults, and accounting for localized site effects such as basin amplification.
- **Vulnerability and exposure mapping** using local authority and satellite data.
- **Secondary perils** such as fire, tsunami and landslides.
- **Displacement of people** caused by earthquakes, how long it lasts and how it affects business interruption.
- **How to improve data availability and processing of big data**, including use of artificial intelligence (AI) and deep learning.

The WRN team regularly publish White Papers[4] and Insights on the results of their research on important topics and recent hazard events, such as the Turkey-Syria earthquake[3], an Annual Review[4] showcasing research projects across all hubs, and events hosted by WTW to showcase research by sponsored students and academics.

Figure 5: **Supporting solutions to real world challenges with science-based research**



[2] www.wtwco.com/en-gb/insights/research-programs-and-collaborations/wtw-research-network#wnss-white-papers
[3] www.wtwco.com/en-gb/insights/2023/02/earth-risks-arising-from-the-2023-turkey-syria-earthquake
[4] www.wtwco.com/en-gb/insights/2023/05/earth-risk

Conclusion

Earthquakes are among the most devastating natural catastrophes, in terms of loss of life, damage to property and interruption to business. That devastation can be multiplied by secondary catastrophes triggered by earthquakes, such as tsunamis and landslides.

But identifying where an earthquake will strike and the level of damage it can cause at a particular location can be difficult, depending on geology, soil type, and the construction and structure of buildings.

Powerful analytics and modeling tools can predict location-specific risk levels and probable losses, while catastrophe risk engineering can help identify the best mitigations to reduce risks.

Alternative risk transfer, such as parametric insurance, can provide a solution for earthquake risks that are difficult or expensive to place through traditional insurance markets.

The WTW Research Network furthers understanding of earthquake risks through science-based evidence. This, in turn, helps our strategic risk consultancy and risk transfer specialists to optimize solutions to fit the needs of individual organizations and locations.

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