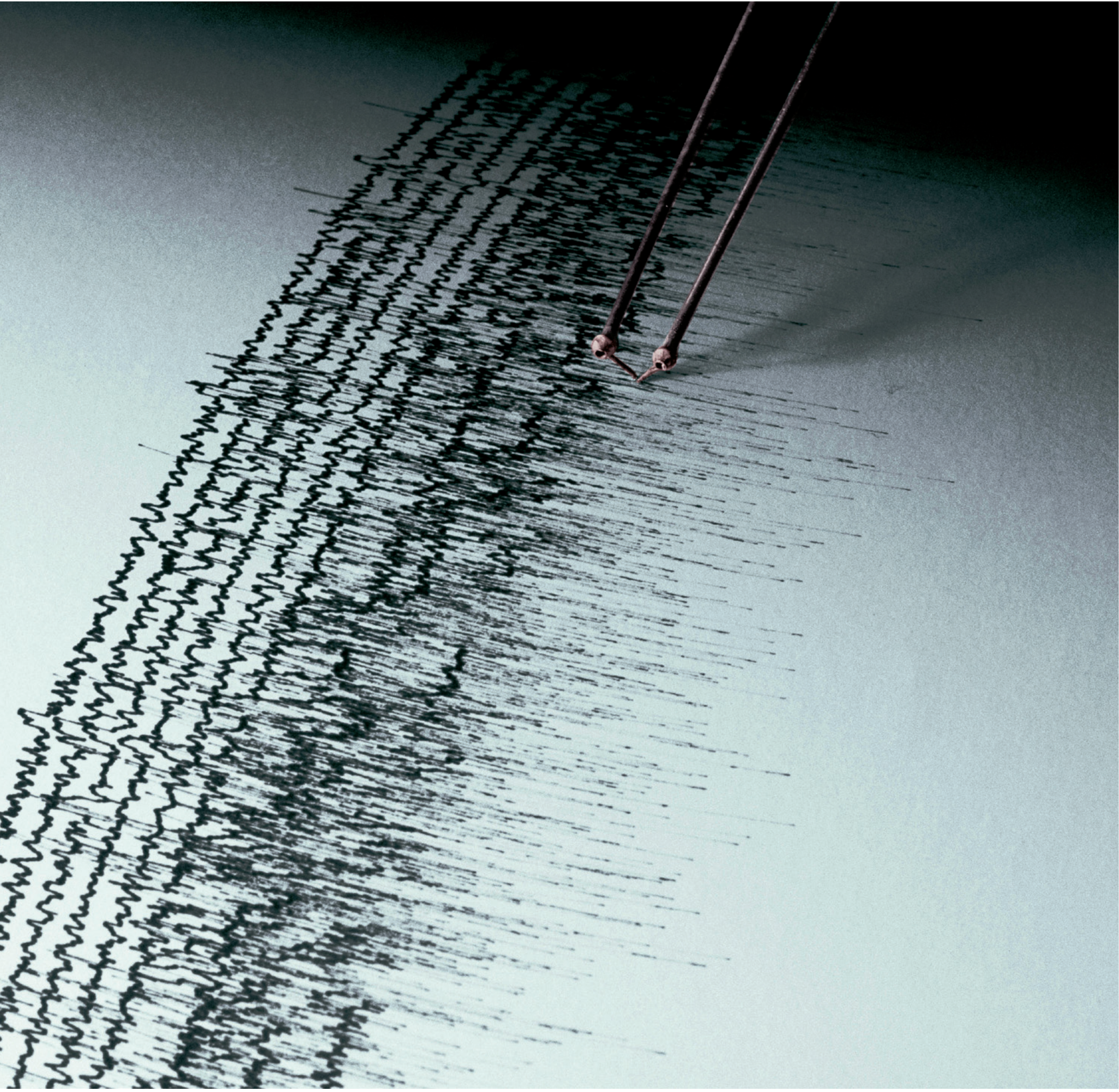

The CatFocus® Earthquake Model

High-Quality Risk Analysis

PartnerRe

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Earthquakes are a threat in many world regions and can have devastating consequences. Despite their potential severity they are however often under-estimated by insurance and reinsurance markets, partly because the high return period of the larger magnitude events creates the illusion that they will not happen in a particular market. In addition, the probabilistic earthquake models, which have become an integral part of risk acceptance and management for insurers and reinsurers, have in relative terms been held back by a number of challenges with respect to both hazard and vulnerability assessment and exposure data. These models can now take some very significant steps forward as a result of improved availability and detail of seismic and building damage data, new research into earthquakes and how they attenuate away from their source, and also improved exposure data quality and resolution.

PartnerRe's proprietary CatFocus® earthquake model has been updated to take full advantage of the new seismic research and data, and is a highly robust, advanced and reliable earthquake risk evaluation tool. This report takes you through this model, highlighting its overall structure and strengths, concentrating in particular on hazard assessment and the model's state-of-the-art systems and methodologies for vulnerability application.

The fact that catastrophe models undergo regular enhancements and expansion in terms of their coverage of perils and regions does not however mean that we can accept model outputs as reality. An understanding of why the models have been revised and what the models are actually doing remains essential to ensure that all parties appreciate what the outputs represent, and therefore that the models are used appropriately as a tool to evaluate risk. That requires transparency and discussion, and at PartnerRe we are committed to both.

Ted Dziurman
Head of Catastrophe, PartnerRe

Introduction

Earthquakes are caused when tension in the Earth's rigid crust is released by sudden movements along narrow zones referred to as faults. Such movements range from micro-cracks at the scale of centimeters, to major ruptures at a scale of hundreds of kilometers. More than a million small earthquakes are observed every year, while the return period of the largest events on a worldwide basis is in the order of decades. These major events have the capability to cause severe social consequences and financial losses representing a considerable percentage of a country's Gross Domestic Product. Reinsurance serves as an important part of the framework for bearing such losses.

Although it is not yet possible to make a reliable prediction of the time of occurrence, location and size of an individual earthquake, researchers have made considerable progress in understanding the temporal and spatial distribution of earthquakes over the long term. Thus regional levels of what we refer to as "seismic hazard" can be assessed with reasonable accuracy. "Seismic risk" is the term used to indicate the economic consequences of an earthquake.

Seismic hazard: the probability that a specified intensity of ground motion will be exceeded within a specified time frame.
Seismic risk: the probability of the economic consequences of an earthquake exceeding a specified level within a specified time frame.

Seismic risk is a function of the seismic hazard within a region, the exposed values in that region and the performance of the buildings when subjected to ground motion (the relationship described by vulnerability curves).

Modeling seismic risk involves specifying the exposure in terms of location and building characteristics, describing the seismic hazard and quantifying the vulnerability of the particular exposure elements. This essentially defines the high-level structure of an earthquake model, as illustrated in **figure 1** on the following page.

While the general structure of an earthquake model remains the same for different regions, the level of detail in a model varies depending on the quality and availability of regional input data. For example, an absence of recent earthquake events or limited availability of the associated data will limit the accuracy of estimating building performance in a region. Our research team has always worked closely with the scientific community to ensure that our proprietary catastrophe models incorporate the latest techniques and data to maximize the accuracy of the risk evaluation in all regions of interest. As described in this report, our CatFocus® earthquake model incorporates advanced methodologies that have further improved the quality and regional coverage of damage data, as well as techniques to reliably process exposure data in all standard data formats.

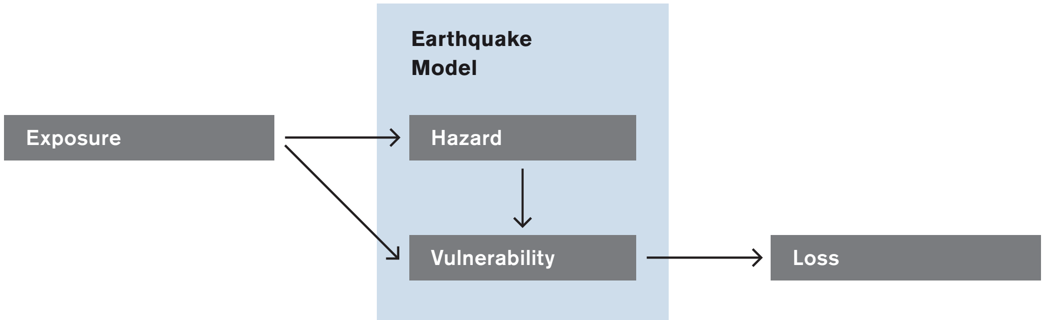
Modeling Seismic Risk at PartnerRe

The CatFocus® earthquake model is a proprietary model developed by PartnerRe to set the foundation for high-quality and consistent seismic risk assessment in all worldwide regions of interest and designed to work with all standard exposure data formats. It is based on scientific expertise as regards all aspects of seismic risk and their complex interdependencies, together with catastrophe modeling know-how and strong underwriting experience.

The model consists of twelve regional models integrated within a consistent framework. These regional models undergo a systematic cycle of review, benchmark and improvement.

This publication provides an overview of the structural components (hereafter "modules") of the CatFocus® earthquake model, concentrating in particular on hazard and vulnerability, and explaining at each stage the most important features and benefits of the approach.

Figure 1
Structure of the PartnerRe CatFocus® earthquake model.



Starting with exposure

The starting point of all risk assessment centers around exposure modeling, involving the systematic compilation, classification and where necessary the disaggregation of the available exposure data of an insurance or reinsurance risk portfolio.

The following key exposure parameters are used in an earthquake model:

- location (geographic coordinates)
- risk characteristics (e.g. construction material and design code)
- covered value (sum insured)
- insurance and reinsurance structure (such as deductibles and limits).

While continuous efforts have been made by insurers and reinsurers towards improved data quality and resolution, outside the U.S. market, it is often the case that individual property portfolios are described in aggregate form as a sum insured per geographic unit (typically a CRESTA zone, district or county) and per property line of business (e.g. residential, commercial or industrial). Aggregate exposure data necessitates the development of robust aggregate models based on a consistent and systematic processing of aggregate data to ensure the meaningful application of the hazard, vulnerability and loss modules.

PartnerRe has developed modeling methodologies that support the processing of all principal industry-standard data formats, including a robust and advanced methodology to deal with aggregate exposure data.

In summary, for detailed exposure data, CatFocus® uses the available information specific to each risk, capitalizing on the richness of this data format to provide the best representation of the hazard and vulnerability on a per risk basis (i.e. for the known geographical locations and risk characteristics). Detailed policy information is optimally used to increase the accuracy of the risk estimation for the given exposure.

For aggregate exposure data, the model applies a weighted spatial disaggregation scheme based on a rigorously developed set of assumptions specific to each region. The more detailed the available exposure data in terms of risk characteristics (split by line of business, insurance cover etc) and the higher the geographic resolution of aggregation zones, the fewer assumptions have to be made at this stage. Typically, we assign disaggregation points according to the smallest geographic units used in population (or building) censuses. This approach additionally provides us with a number of published measures on the relative importance of each point relating to exposure concentration, thus allowing for the development of suitable weighting schemes. In this way, we manage to significantly improve the representation of aggregate exposure data.

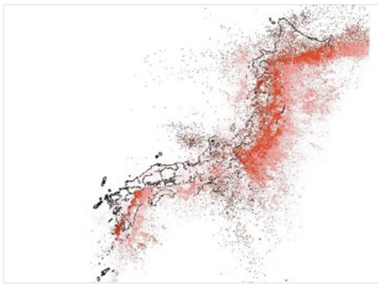
Hazard Modeling

To represent the seismic hazard, a comprehensive list of probable earthquake events, each with an associated magnitude, hypocenter location and frequency/return-period, is generated. For each event in the resulting earthquake catalogue, appropriate ground motion attenuation models are applied as well as local soil modification factors (the full process is summarized below in **figure 2**). The result is ground motion intensities for all locations or disaggregation points (in the case of aggregated exposure data) and for all events in the earthquake catalogue.

Figure 2
Overview of how the CatFocus® earthquake model determines seismic hazard, with image examples from Japan.
Source: Partner Re; Shapefile from © GfK GeoMarketing GmbH

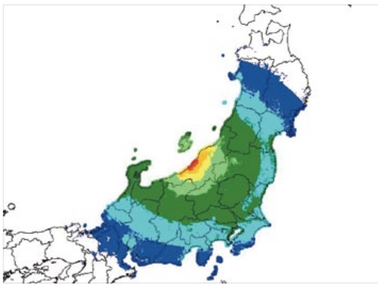
Stochastic earthquake catalogue

As large earthquakes are rare, risk modeling cannot be based on historically observed events alone. Based on the magnitude-frequency distribution of all available events, synthetic catalogues are generated comprising tens of thousands of years of stochastically created earthquakes.



Seismicity

For every event and all locations



Seismic intensity distribution

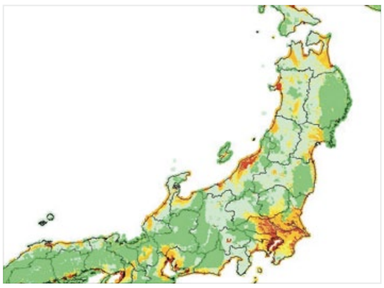
Ground motion calculation

Ground motion level on Bedrock

The spatial distribution of expected ground motion (shaking) has to be determined for each event in the stochastic catalogue. Formulas called ground motion prediction equations or attenuation functions are used to calculate the level of ground motion depending on the characteristics of the earthquake source and the distance from the epicenter.

Local soil modification

It has been observed that local soil conditions influence the resulting ground motion to a great extent. The ground motion calculations must therefore be adjusted to take the local surface geology into consideration.



Surface geology

The stochastic event catalogue

In an earthquake, part of the released energy is transferred away from the source by emanating seismic waves. Utilizing records of these waves, Charles Richter first introduced the concept of an earthquake magnitude scale in the 1930s as a means to provide a single measure with which to describe the relative size of earthquakes.

Although the now commonly used Moment Magnitude (M_W) is based on different parameters[1], its logarithmic basis is the same: a tenfold increase in ground motion amplitude corresponds to an increase of one unit on the magnitude scale.

The number of earthquakes per year in any region decreases rapidly with increasing magnitude (see **table 1**); an observation that was first quantified in 1944 by the seismologists Beno Gutenberg and the aforementioned Charles Richter. Their magnitude-frequency finding is commonly referred to as the Gutenberg-Richter relationship.

Table 1
Worldwide average annual number of earthquakes by Moment Magnitude band, based on
(a) observations since 1900,
(b) observations since 1990, and
(c) estimations.
Source: The United States Geological Survey (USGS)

Moment Magnitude (M_W)	**Average annual number of earthquakes**
8 and higher	1[a]
7 – 7.9	17[b]
6 – 6.9	134[b]
5 – 5.9	1,319[b]
4 – 4.9	13,000[c]
3 – 3.9	130,000[c]
2 – 2.9	1,300,000[c]

While this relationship accurately describes seismicity from the regional to the worldwide scale, there is an ongoing discussion among seismologists as to whether the relationship also holds true for individual faults. Some believe that the behavior of individual faults is better described by repeating occurrences of earthquakes of characteristic size (e.g. Wesnousky[2]). Whether or not this holds true, the latter approach requires high-quality data for each fault in question; this is often not available on a regional or country basis. The CatFocus® earthquake model uses both approaches depending on data availability. By utilizing various assumptions, we can also assess the sensitivity of the model results to individual input parameters. This gives PartnerRe an independent and comprehensive view of the consequences of new scientific developments on seismic risk estimation (e.g. The Uniform California Earthquake Rupture Forecast [UCERF2][3] and the 2008 Update of the United States National Seismic Hazard Map[4]).

Once a stochastic set of earthquake events satisfying the Gutenberg-Richter magnitude-frequency distribution of the specified region has been generated, the individual events have to be further parameterized to simulate other aspects characterizing realistic earthquake scenarios.

1 M_W refers to the seismic moment given by the product of the average displacement (slip) along the fault during an earthquake, the surface area of rupture and the shear modulus of the local rocks. This measure can be related to the total energy released in an earthquake.

2 Wesnousky, S.G., (1994). The Gutenberg-Richter or characteristic earthquake distribution, which is it?, Bull. Seism. Soc. Am. **84**, 1940 – 1959.

3 2007 Working Group on California Earthquake Probabilities, (2008). The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2), U.S. Geological Survey Open-File Report 2007–1437 and California Geological Survey Special Report 203.

4 Petersen, Mark D., et al, 2008, Documentation for the 2008 Update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008 – 1128, 61 p.

The Gutenberg-Richter relationship

Log 10 (N(M,T)) = a(T) – b M

Where

N is the cumulative number of earthquakes of Magnitude M and greater in the specified region and time range T

a is a constant that describes the overall level of seismic activity

b is a constant that denotes how much more unlikely events become with increasing magnitude; b is generally considered to be around 1.

The formula in its original form indicates that there is a likelihood of earthquakes of any magnitude occurring if a long enough time span is considered. As magnitude depends on the length of active rupture along a particular fault, seismologists are able to take advantage of geological information to assess the maximum possible earthquake magnitude for active faults. This additional parameter has to be incorporated into the Gutenberg-Richter relationship before the formula can be used to project statistics over long time periods.

Figure 3 illustrates these concepts. The logarithmically scaled vertical axis displays the number of earthquakes within a given period of time which exceed a magnitude indicated on the horizontal axis. Whereas the original Gutenberg-Richter relationship corresponds to a linear relationship steered by the constants a and b (yellow line), modified forms result in a bending of the graph towards the maximum magnitude, in this example 8.5 (red line).

From the above formula it can be understood that three parameters are essentially needed to describe the seismicity of a region: the general level of seismic activity (constant a), the magnitude-frequency distribution (constant b) and the maximum expected magnitude. These parameters are derived from catalogues containing historically observed and instrumentally recorded earthquakes.

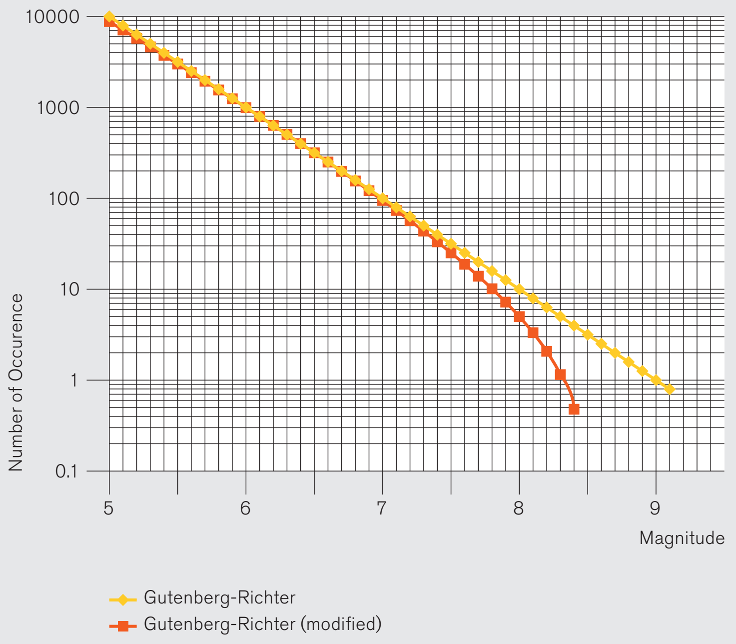


Figure 3
Graph showing the Gutenberg- Richter relationship for a specific region and time range. The red curve is adjusted to take into consideration the strongest possible earthquake event in the region.
Source: PartnerRe

Earthquake epicenters can be placed at random within the specified source zone or distributed statistically along a mapped fault-line. Similarly, hypocenter depth is distributed around a target depth specified for the source zone. The actual length of the active fault rupture can be derived from the magnitude according to published relationships (e.g. Wells & Coppersmith[5]). The derivation of fault mechanism (strike-slip, thrust- or normal-faulting) as well as fault strike and dip parameters (directional parameters defining the orientation of geologic features, including fault planes) stem from geological information. As a result, a stochastic earthquake catalogue can be created at the same level of detail as today's instrumental observations, but representing a much longer time period.

Ground motion calculation and local soil modification

To estimate the level of ground motion at any one location requires knowledge of how the energy released from an earthquake travels through the ground and away from the source. Although the underlying physics of seismic wave propagation is well understood, the three-dimensional wave-field emanating from an extended source (i.e. the fault rupture plane) in the presence of a heterogeneous media (i.e. the specific local rock, soil types and structures) can become extremely complex. Realistic simulations of seismic wave propagation have therefore only recently become possible. Such simulations rely on the availability of detailed information on the underground structure and earthquake rupture process. Three-dimensional wave-field studies can therefore only be carried out in specific areas and for very few earthquake scenarios. However, they have helped to improve understanding as to how ground motion is affected (amplified or reduced) by local geology (see **figure 4**).

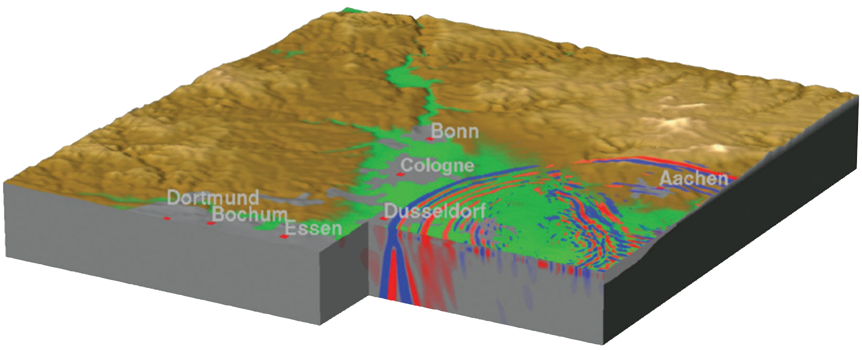


Figure 4
Simulation of a three-dimensional seismic wave-field emanating from an earthquake in the Cologne Basin, Germany. The level of complexity is clearly visible; because of this, earthquake models rather focus on modeling the decrease in peak ground motion with distance from the epicenter of an earthquake.
Source: Michael Ewald

5 Wells, D.L. and J. Coppersmith (1994). New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, Bull. Seism. Soc. Am. **84**, 974–1002.

As three-dimensional wave-field studies are not universally available, a more simplified approach must be taken for engineering and seismic hazard assessment purposes. Ground motion at any point is commonly considered to be a function of the combined effects of source (earthquake magnitude, hypocenter depth and fault mechanism), path (attenuation of seismic waves with distance) and site (amplification effects based on the uppermost layer of soil). Statistical analyses carried out on large numbers of seismic recordings from compatible geological and tectonic regions allow for the quantification of the dependence of ground motion on these factors.

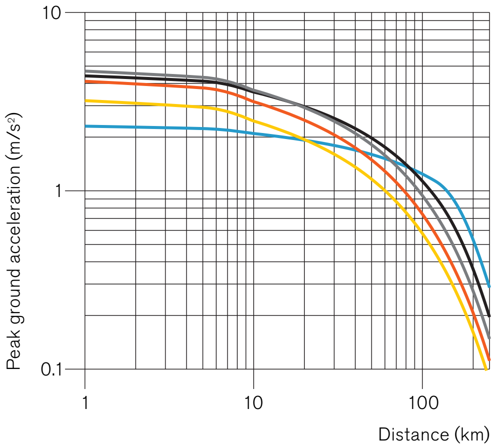


Figure 5
At equal distances from the same earthquake event, ground movement varies depending on the local soil condition. Soil type is therefore an important parameter to add into attenuation functions, which are used to estimate ground shaking at all risk locations. Source: PartnerRe

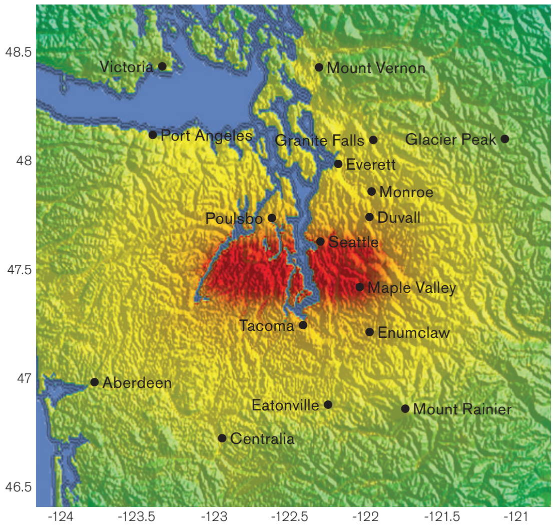
Figure 5 shows an example of varying attenuation behavior for an identical earthquake source in the presence of differing soil conditions. The derived functions are commonly referred to as "attenuation relationships" or "ground motion prediction equations". These functions allow for the calculation of expected peak ground motion measures – such as peak ground acceleration (PGA), peak spectral acceleration (PSA), peak ground velocity (PGV) and seismic intensity – at any given distance from the source, along with a sound quantification of the uncertainty.

In the CatFocus® earthquake model, a regionally varying set of attenuation functions is used to model ground motion in a deterministic way for each event in the earthquake catalogue at the exposure locations. The attenuation functions within the model are reviewed on a regular basis and the ground motion modeling is accordingly updated as new scientific knowledge becomes available (e.g. NGA project[6]). The accompanying uncertainty is evaluated and passed on to the model's loss calculation module.

6 The New Generation Attenuation Project. Earthquake Spectra, February 2008, Issue 1, pp. 1–341.

Figure 6
Modeled ground motion intensity distribution from CatFocus® for an earthquake scenario in the Seattle area, U.S. The conversion of peak ground acceleration to Modified Mercalli Scale intensity and the associated color scheme are given in the table to the right of the image; these are consistent with those used in shake maps published by the USGS.
Source: PartnerRe, USGS

CatFocus® earthquake scenario in the Seattle fault zone.
Magnitude: 7.2, N47.5° W122.6°, Depth: 10km,
Length of active rupture: 60km.



Perceived Shaking	Potential Damage	Peak Acc. (%g)	Peak Vel. (cm/s)	Instrumental Intensity
Extreme	Very Heavy	>124	>116	X
Violent	Heavy	65–124	60–116	IX
Severe	Moderate/ Heavy	34–65	31–60	VIII
Very Strong	Moderate	18–34	16–31	VII
Strong	Light	9.2–18	8.1–16	VI
Moderate	Very light	3.9–9.2	3.4–8.1	V
Light	none	1.4–3.9	1.1–3.4	IV
Weak	none	.17–1.4	0.1–1.1	II–III
Not felt	none	<.17	<0.1	I

Converting ground motion to seismic intensity

In instrumental seismology, PGA or PSA are a natural choice for an easily assessable measure to characterize ground motion. However, seismic intensity scales are commonly used to describe and rate the actual effects of ground motion. Before the widespread deployment of seismometers, such scales were based exclusively on descriptive measures of ground motion effects, these scales are however now tied to physical ground motion measures according to conversion formulae, such as that proposed by Wald et al.[7] The intensity scales most commonly used today are the Modified Mercalli Scale (Americas), the European Macroseismic Scale, EMS-98 (Europe) and the JMA scale of the Japanese Meteorological Agency (Japan).

The kind of intensities calculated by this approach are commonly referred to as "instrumental intensity" and are published globally in shake maps such as those provided by the USGS. **Figure 6** depicts an example shake map from the CatFocus® earthquake model for an earthquake scenario in the Seattle area of the U.S. The supporting conversion of two physical ground motion measures – peak ground acceleration (PGA) and peak ground velocity (PGV) – into Modified Mercalli intensity is given in the table adjacent to the map. The CatFocus® earthquake model utilizes this conversion to express modeled ground motion in terms of intensity, which is subsequently linked with building vulnerabilities.

By developing the entire seismic hazard module, PartnerRe has an in-depth understanding of the underlying assumptions made at each stage and can therefore validate the modeled ground motions which then feed into the vulnerability module.

7 Wald, D. et al., Earthquake Spectra, Volume 15, No. 3, August 1993.

Vulnerability Modeling

Vulnerability modeling builds the interface between the hazard, exposure and loss modules of the earthquake model, translating the level of seismic hazard and value at risk (exposure data) into an estimation of monetary loss. It does this by relating the ground motion (seismic intensity) generated by an earthquake at a given location to the level of damage likely to be sustained by buildings at this location.

Vulnerability curves are the most common way of representing the relationship between seismic intensity and building damage. These curves are derived as a best fit to either observed (Empirical curves) or simulated (Calculated curves) earthquake damage data at different levels of ground motion.

In insurance and reinsurance, global exposures are characterized by large groups of similar, but not identical, risks, often with limited access to detailed structural information on any one individual risk. This limits the applicability of Calculated vulnerability curves, which require a great number of building specific input parameters (e.g. natural frequency of oscillation, degree of hysteretic damping[8] and inter-storey drift[9]) to fully describe each risk. Empirical methodologies on the other hand are directly derived from past earthquake events in the region of interest and thus inherently incorporate the particularities of the local risks. If available, they therefore more reliably represent future damage levels and are often better suited to the development of region-specific vulnerability curves for various building types.

Empirical vulnerability methodologies are based on the statistical analyses of observed damage data and distributions[10] from past earthquake events.
Calculated vulnerability methodologies define damage distributions through the numerical simulation of the performance of typical building structures given varying ground motions (represented in the form of earthquake loads or displacements). The design specifications of buildings are an important factor in these calculations.

8 Hysteretic damping describes the energy of a vibrating structure lost in each cycle of the vibration.
9 Inter-storey drift describes the relative horizontal displacement between two adjacent stories of a building divided by the story height.
10 For conciseness and usability, building damage data is typically reported both by type of building and damage state (typically there are five discreet levels of damage). The damage distribution shows the percentage of buildings in a region that fall within each damage state (the data can also be displayed by building type).

Figure 7
Examples of different load-bearing structural systems.
Source: Faye Karababa

1 Timber frame
2 Stone masonry
3 Confined brick masonry
4 Reinforced shear wall at ground floor
5 Reinforced concrete frame with in-filled brick masonry walls
6 Steel frame


1


2


3


4


5


6

The vulnerability module

PartnerRe collaborated with world experts in the field of vulnerability modeling to develop the Global Earthquake Vulnerability Estimation System (GEVES)[11], a methodology that delivers Empirical vulnerability curves for a wide range of different building types, occupancy classes and regions. For building types where limited observed damage data is available, a hybrid approach was developed augmenting the observed damage data with simulated data from Calculated vulnerability approaches. This methodology is now an integral part of the vulnerability module of the CatFocus® earthquake model. The principal strengths of GEVES can be summarized as follows:

- It is a practical application tailored specifically to the needs of insurance and reinsurance risk modeling.
- It is based on a large pool of data compiled from published reports and the regional studies of our expert collaborators.
- Vulnerability curves can be easily enhanced when new data become available.
- Data collection and processing is highly transparent.
- Developed curves are calibrated against real earthquake losses.
- The method explicitly considers uncertainty.

The vulnerability curves derived through GEVES can be readily applied to detailed exposure data, since the range of curves developed adequately captures the information typically provided within such data. For aggregate exposure data, PartnerRe has developed a methodology to convert the relevant detailed curves into aggregate vulnerability curves.

PartnerRe's development of detailed vulnerability curves for groups of insured risks is based on the assumption that buildings of similar structural characteristics are likely to perform similarly under the same ground motion/seismic intensity and site conditions[12]. The primary characteristics of buildings that significantly affect their performance in an earthquake are:

- construction material
- load-bearing structural system (see **figure 7** for examples)
- building design and design code
- number of stories
- occupancy and use (these inherently reflect construction quality and type).

11 Spence, R., So, E., Jenny, S., Castella, H. and Booth, E. (2008). The Global Earthquake Vulnerability Estimation System (GEVES): an approach for earthquake risk assessment for insurance applications, Bulleting of Earthquake Engineering (2008), Vol. 6, pp. 463–483.

12 Coburn, A. and Spence, R. (2002) Earthquake Protection, Second Edition, John Wiley & Sons Ltd., West Sussex.

Mean Damage Ratio (MDR)

After an event, the resultant damage is assessed by engineers. To expedite and standardize this process and to allow for the statistical processing of damage data, protocols are typically drafted in advance. The protocols enable the ultimate classification of inspected buildings by type (via a pre-defined list of options pertaining to the most common building characteristics, such as materials, structural system, age and number of floors) and level of damage. Damage is typically classified into discreet classes known as damage states.

Each damage state is defined via both qualitative (e.g. location and orientation of cracks) and quantitative (e.g. number and width of cracks) indicators specific to each building type, which guide the process of assigning the damage state. There are usually five distinct damage states. The overall damage distribution for the affected area, i.e. the percentage of all buildings within each damage state, can then be ascertained (**figure 8**). Damage distributions can also be obtained for individual building types, given the additional information available in the completed protocols.

While damage states provide a means to classify damage observations and compare them in relative terms, they do not sufficiently represent the continuous nature of damage. Earthquake engineers therefore also apply a percentage scale which helps to convert the discreet damage states into a continuous damage variable. A percentage range is assigned to each state depending on the building type. The mean of this range – the central damage factor (CDF) – is then defined (example in **table 2**).

If we know the damage distribution for a specific building type subjected to a known level of ground motion, as well as the defined CDF applicable to each state for that building type, a mean damage ratio (MDR) – the weighted average of all damage states for that building type – can be developed. For each building type we therefore obtain the MDR corresponding to a known level of ground motion. By compiling distributions from multiple earthquake events (i.e. for all levels of ground motion) we can similarly define a spectrum of corresponding MDRs for all possible levels of ground motion.

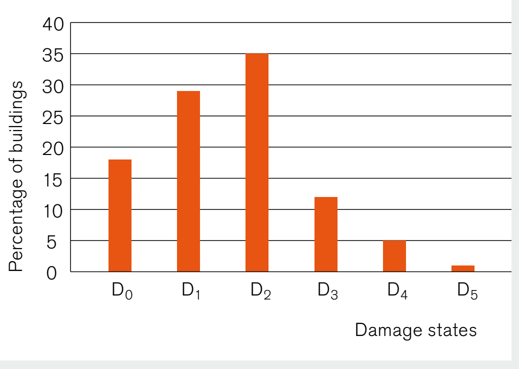


Figure 8
An example of the distribution of building damage by damage state following an earthquake event. The corresponding damage state definitions are shown in **table 2**. Such data can be presented for all buildings and/or by building type.
Source: PartnerRe

Table 2
A typical high level definition of building damage states, used by earthquake engineers to assign specific and consistently applied damage levels[13], together with examples of damage factor range and central damage factors for damage states 1 to 5 for a specific building type.
Source: Dolce et al. (2006)[14]

Damage state	Basic description	Damage factor range	Central Damage Factor (%)
D_0	No damage	0	0
D_1	Negligible to slight damage	0 – 5	2.5
D_2	Moderate damage	5 – 20	12.5
D_3	Substantial to heavy damage	20 – 50	35.0
D_4	Very heavy damage	50 – 95	72.5
D_5	Destruction	95 –100	97.5

13 Grünthal, G. (Ed.) (1998) European Macroseismic Scale 1998 EMS-98, European Council, Luxembourg.
14 Dolce, M., Kappos, A., Masi A., Penelis, G. and Vona, M. (2006), Vulnerability assessment and earthquake scenarios of the building stock of Potenza (Southern Italy) using Italian and Greek methodologies, Engineering Structures, Vol. 28, pp. 357–371.

Table 3
Number of standard and most common building types grouped by construction material, as defined by the Global Earthquake Vulnerability Estimation System (GEVES)[15].
Source: PartnerRe

Category	Timber	Masonry	Reinforced concrete	Steel or metal frame	Composite
Number of building types	2	3	14	7	2

GEVES defines 28 standard (representing the most common) building types (**table 3**) and 14 occupancy classes (3 residential, 4 commercial and 7 industrial) for 33 regions around the world. Additional building types are defined for regions where the standard set does not fully describe the exposed risks, such as for traditional Japanese housing.

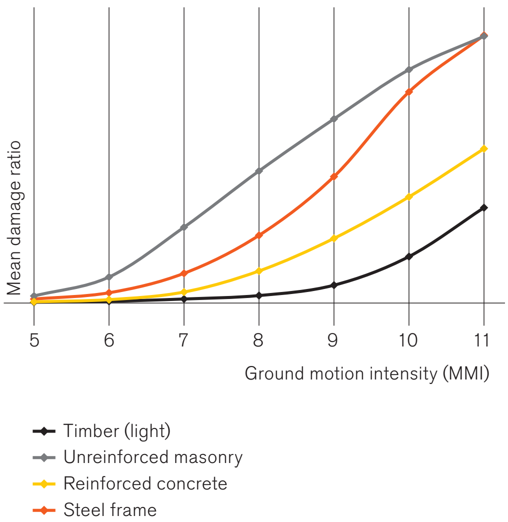


Figure 9
An example of detailed vulnerability curves relating to common building types in the California and Washington-Oregon regions of the U.S. The curves show the variation in the mean damage ratio (MDR) experienced by buildings of different construction given the same intensity of ground motion.
Source: PartnerRe

A database of all the available earthquake damage data by defined building type and region, adjusted to take into account the data quality and changes over time in regional building practices was subsequently developed as part of the GEVES methodology. In cases where regional data was insufficient to provide the desired level of detail, the data was augmented by global data based on careful consideration of regional building types. The damage data was then summarized in the form of estimated mean damage ratios (MDR) for different levels of ground motion (based on the Modified Mercalli Intensity (MMI) scale), building type and region. See example in **figure 9**.

In cases where exposure is provided as a total sum insured by geographical region and property line of business, it is not possible (as it is with detailed risk data) to directly apply the previously described detailed vulnerability curves that relate to individual building types.

In order to accommodate such aggregated risk data, PartnerRe has also developed aggregate vulnerability curves based on the methodology summarized in **figure 10** on the following page.

15 Coburn, A. and Spence, R. (2002) Earthquake Protection, Second Edition, John Wiley & Sons Ltd., West Sussex.

Figure 10
Overview of the methodology for the development of aggregate vulnerability curves, with examples. Such curves are developed when exposure data is supplied in an aggregate format. Within each aggregate vulnerability curve, the variation in actual building type is included by way of a weighting calculation.
Source: PartnerRe

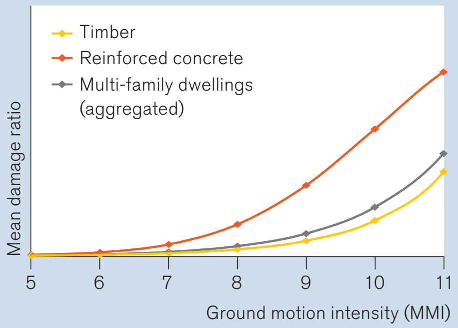
Step 1: Obtain a percentage distribution of the building types within each of the 14 occupancy classes defined in GEVES for the region of interest.

Distribution of building types by occupancy class

	Single-family dwellings	Multi-family dwellings	Commercial retail	Commercial warehouse	Heavy industrial indoors	Light industrial indoors
Timber frame	60%	75%	35%	5%	–	–
Reinforced concrete frame	5%	25%	55%	70%	65%	40%
Unreinforced masonry	35%	–	2%	–	–	–
Steel frame	–	–	8%	25%	35%	60%
Total	100%	100%	100%	100%	100%	100%

Step 2: Use the percentages to weigh each individual building vulnerability curve in order to obtain a single vulnerability curve per occupancy class.

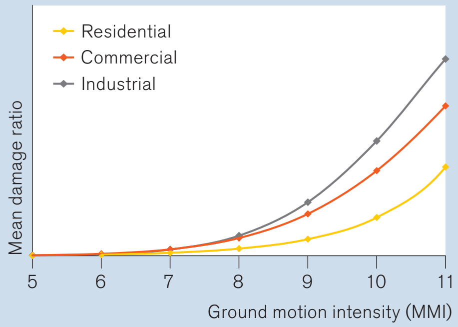
Weighted average curve for multi-family dwellings



Step 3: Obtain a percentage distribution of the occupancy classes within each line of business (residential, commercial and industrial). These distributions were derived through publicly available building and business census data in each region.

Step 4: Use the percentages to weigh each individual vulnerability curve for each occupancy class (obtained in the step above) in order to develop a single vulnerability curve per line of business.

Aggregate vulnerability curves for residential, commercial and industrial property lines for the California region of the U.S.



For insurance and reinsurance purposes, where loss in monetary terms is of primary interest, it is necessary to relate the level of structural damage (expressed as a MDR) to economic loss. This is achieved by assuming that when a building is damaged at 100%, the economic loss will equal the sum insured, i.e. the replacement cost of the building (this will include not only the cost of rebuilding, but also the cost of demolition and debris removal). The economic loss to a particular building type subjected to a given level of ground motion can therefore be evaluated as:

Economic loss = MDR* Average replacement cost

However, while the MDR accurately represents the mean level of damage within a group of buildings of similar characteristics, located in the same region and experiencing the same level of ground motion intensity, in reality, no two buildings will behave in exactly the same way when subjected to the same ground motion conditions[16]. Observed damage levels will be spread around the mean value; this spread is typically shown to have a quadratic relationship to the MDR, with its largest value at MDR = 50%[12]. See **figure 11**.

Therefore at an MDR of 50%, some buildings may be nearly undamaged while others are heavily damaged, averaging out at 50%. However, at much higher (90%) or lower (10%) MDR levels, it is unlikely that such variation in damage levels will be observed.

The higher the accuracy and level of detail when defining building types, as well as the quality of damage data – influenced by the extent to which the data has been compiled from recent earthquake damage surveys which tend to follow more methodologically sound processes – the lower the spread of observations around the MDR. The GEVES methodology accordingly models the relationship between the MDR and the likely spread of damage around it based on estimations of these aspects, and incorporates this uncertainty in the final loss estimations.

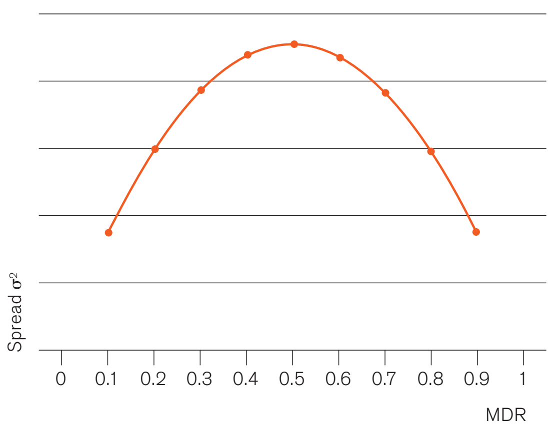


Figure 11
Quadratic relationship between mean damage ratio (MDR) and its spread.
Source: PartnerRe

16 This is partly because of inherent differences in the properties of the building materials used, as well as differences introduced through building construction.

Conclusion

Understanding what determines the output of a model and knowing the associated uncertainty has always been important to PartnerRe and is the reason we developed our proprietary CatFocus® models. Combined with the outputs of vendor models and market opinion, we are thus able to offer clients an informed and comprehensive view of risk. As new knowledge and/or data becomes available, we analyze and incorporate this into our proprietary models based on a combination of internal research and underwriting expertise, and always in close collaboration with the scientific community.

Seismic risk is determined by a complex interaction of seismic hazard, exposure and vulnerability. Evaluation of this risk for insurance and reinsurance is complicated by incomplete hazard, damage and exposure data. CatFocus® reliably addresses many of the pre-existing weaknesses in earthquake modeling. The model benefits in particular from GEVES, a sophisticated methodology supporting the vulnerability module (delivering statistically robust Empirical, rather than Calculated, curves) and from a spectrum of methodologies that reliably process both detailed and aggregate exposure data formats.

Earthquake glossary

Hypocenter
Location underground where the rupture starts. Also called the focus of an earthquake.

Epicenter
Vertical surface projection of the hypocenter. Not necessarily the place of strongest shaking.

Strike
Direction of the surface fault projection with respect to geographic north.

Fault plane
Planar idealization of the interface between the blocks on which the rupture occurs.

Dip
Inclination of the fault plane with respect to the horizontal.

Active fault length
Length of the part of a fault which is activated in an earthquake event.

Fault mechanism
Determined by the differing relative motions of the blocks.

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