Mapping landslides for the insurance industry – lessons from earthquakes

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ABSTRACT

Earthquake insurers currently can quickly identify 'risk' for a building street address by using probabilistic models based on 1) proximity to earthquake sources, 2) likelihood of earthquake occurrence, 3) attenuation of shaking with distance, and 4) amplification effects caused by site conditions. Loss estimates are based on building type, age, and use. Earthquake insurance coverage price is based on risk of loss and value of property. Landslides currently are uninsured because risk of loss is not quantified; therefore, insurance coverage price cannot be set. The insurance industry needs probabilistic models of landslide processes that quantify the likelihood that they will occur and the extent of damage that will result.

The earthquake example should provide geoscientists and engineers with valuable lessons of probabilistic models of landslide initiation and movement. Loss estimates will depend in part on the nature of buildings sitting on the landslide and in part on the amount and duration of ground movement. Earthquakes tend to be catastrophic with a single event resulting in widespread damage that ranges from slight to severe over a period of a few tens of seconds. Landslides tend to be localized with a single event resulting in damage to relatively few buildings, but may occur over a period of days to years. Landslide triggers can be regional, but landslide damage remains localized.

Local governments effectively tend to become insurers by providing funds for response, recovery, and reconstruction following landslide events. The same type of geoscience regarding landslide risk management is needed for the private insurance industry as for local governments. IAEG Commission No. 1, Engineering Geological Characterisation and Visualisation, is taking a systematic approach in an attempt to apply earthquake lessons to quantifying landslide occurrence and severity.

Keywords: insurance, landslide, earthquake, hazard, risk, modeling

1 INTRODUCTION

Landslides are the only major uninsurable natural hazard as of 2008. Insurance coverage for earthquakes was not widely available before the insurance industry had sufficient knowledge about the frequency and extent of earthquake damage to establish the price for insurance products. The purpose of this paper is twofold. First, we describe the process of interaction between representatives of the insurance industry and the science and engineering community which led to a common understanding of earthquake processes and actuarial needs. Second, we present the concept of landslide insurance in the context of the earthquake insurance success.

Landslide hazards are widespread; Figure 1 shows areas of moderate and high landslide incidence and susceptibility in the United States (Radbruch-Hall *et al.* 1982; Godt 1997) displayed as a single unit. Figure 2 shows the United States earthquake hazard expressed as probabilistic ground motion intensity (http://earthquake.usgs.gov/research/hazmaps/interactive/). Both of these maps display hazard, with only an implicit indication of risk. Hazard refers to processes which have the potential to cause damage or injury, whereas risk refers to exposure of facilities, people, livestock, and functions to damage, injury, interruption, or loss from occurrences of the hazardous processes. Similarities between earthquake hazard maps and landslide hazard maps were recognized by Perkins (1997).

The landslide hazard map on Figure 1 and the earthquake hazard map on Figure 2 differ in two fundamental ways: a) hazard intensity and b) hazard frequency. The landslide hazard map denotes areas where landslides have occurred in the past (incidence) or where slope and geology conditions suggest that landslides could occur (susceptibility) without regard to how much movement might occur in the future or how likely such movement might be. The earthquake hazard map displays the distribution of expected earthquake accelerations (hazard intensity) corresponding to a 10% probability of exceedance in 50 years (hazard frequency), which is ground motion with an average recurrence of 475 years or an annual frequency of 0.002107.

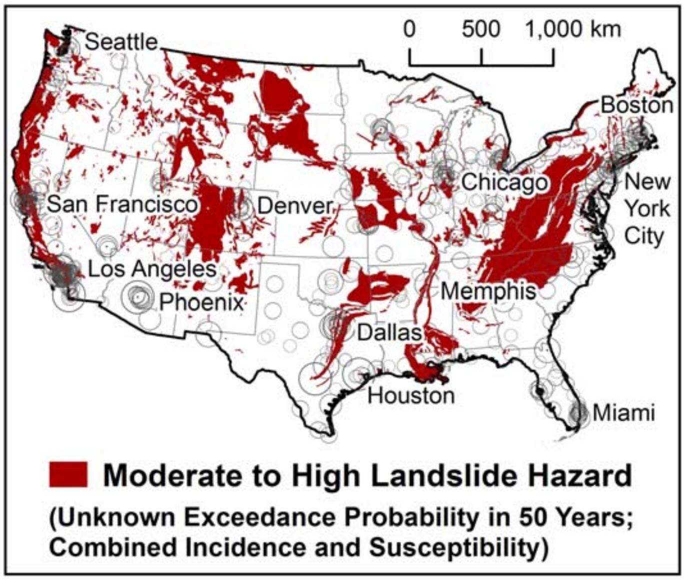

Figure 1. Areas of moderate to high landslide hazard in the United States. Landslide hazard areas modified from Godt (1997).

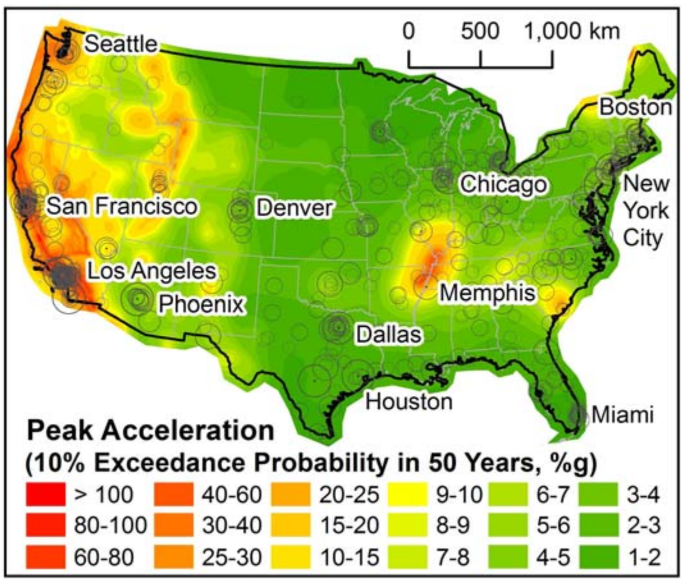

Figure 2. Earthquake hazard in the United States displayed as peak horizontal acceleration corresponding to 10% exceedance probability in 50 years. Earthquake acceleration data from U.S. Geological Survey website (http://earthquake.usgs.gov/research/hazmaps/interactive/).

2 EARTHQUAKE INSURANCE OVERVIEW

Insurance products are offered by private insurers for a price that includes product development, marketing, servicing, administration, and profit. The cost of servicing an insurance product includes the amount that a provider will have to pay in claims, which is a function of the value of insured damage and the frequency and extent of loss.

Past experiences with types of losses that happen frequently, such as house fires or automobile accidents, may allow insurers to quantify risk of loss based on similar types of building construction and uses or driving conditions. Damaging effects of infrequent processes, such as hurricanes and earthquakes, require comprehensive models because risk of loss cannot be based on past experiences. Inventories of at-risk facilities, populations, and functions also are needed to quantify natural-process damage and loss risks. If model results are not accurate, then private insurers cannot quantify the risk. Viable insurance products cannot be offered even if model results are accurate, but the policy premiums are higher than what people are willing to pay.

Challenges for insurers include adverse selection, moral hazard, and correlated risk (Kunreuther 1998). Adverse selection refers to policies being purchased only by owners of property that is likely to be damaged. Moral hazard refers to a relaxation in the level of care or concern on the part of an individual after insurance is purchased. Correlated risk refers to concentrated single-event damage. Since basically all property inundated by a 100-year flood will be damaged, and if only people with property inside the floodplain buy flood insurance, it stands to reason that a single flood will produce a large number of claims. Similar adverse selection and correlated risk exist in earthquake-prone areas (Roth 1998).

Earthquake insurance products were developed by insurance companies after seismologists, geologists, and engineers were able to provide suitable information to insurance actuaries so that estimates of earthquake shaking could be combined with building vulnerability to create models of earthquake-induced loss. A wide gap existed between the needs of the insurance industry and the interests of the science and engineering community. This gap was closed by an effort that brought together insurance actuaries, seismologists, geologists, engineers, planners, lawyers, and politicians to discuss topics such as

Seismology and geology	Earthquake source mechanisms; the nature of shaking related to earthquake magnitude; attenuation of shaking with distance away from the epicenter; the severity of shaking related to proximity to fault traces; the severity of shaking related to local geologic conditions
Engineering	Building response to earthquake shaking related to age, number of stories, and construction type; effectiveness of building codes
Sociology and public policy	Stakeholder identification in hazard mitigation; land use zoning; building code development and

	enforcement
Insurance	Relativity of building damage in terms of distance from fault traces and earthquake epicenters; vulnerability of buildings to damage in terms of age, height, and construction type; estimates of probable maximum loss

These discussions allowed earthquake researchers to understand the needs of the insurance industry. Experience with earthquake damage since insurance was made available has resulted in improved knowledge about earthquake processes and building responses. It also has resulted in improvements in the information gathered after earthquake disasters have occurred. For example, details of building damage are collected so that correlations can be made among geologic site condition, earthquake ground motion level, and building age, height, and type. Such information is used to improve earthquake zoning regulations and building code provisions.

Earthquakes are recurring events. The locations in the United States where earthquakes are expected to occur can be deduced from the hazard map on Figure 2. Certain building types (unreinforced masonry) tend to experience substantially greater damage than other types (wood frame) when exposed to the same ground motion, other things being equal (building height, distance from seismic source, geologic site conditions). The insurance industry relies on models for the knowledge of earthquake ground motion and site effects and the predicted recurrence intervals of earthquake events. The basic elements of an earthquake loss estimation model consist of:

(1) Identification ground motion at a location on an annualized basis in terms of acceleration including distance attenuation and site amplification effects;

(2) Expected damage to building structures and contents in terms of percentage of loss including consideration of age, type, number of stories, and usage (for commercial buildings).

(3) Estimation of value of building structures, contents, and functions, and replacement or repair cost.

3 LANDSLIDE INSURANCE CONCEPT

Landslide insurance is mentioned by Lee and Jones (2005) with reference to government programs in New Zealand, France, and the United States. Landslide damage is excluded from essentially all types of private property insurance. This lack of availability of insurance coverage for landslide risk probably results from a combination of factors, such as insurance companies not being able to develop accurate models of landslide hazard (location, magnitude and frequency of occurrence) or extent of damage to buildings sitting on landslides that move.

Jelínek *et al* (2007) discuss risk mapping of landslides in central and eastern European countries. They note that “A landslide hazard map ideally indicates the probability of landslides occurring in a given area at a given time or with a given frequency. A hazard map, however, may be as simple as a map that uses the locations of old landslides to indicate potential instability, or as complex as a quantitative map incorporating probabilities based on variables such as rainfall thresholds, slope angle, soil type, and levels of earthquake shaking” (p. 11). The summary of six countries indicated that landslide inventory maps were common; mention of landslide hazard maps implied that probability of landslide occurrence in a specific time period was omitted.

Earthquakes and hurricanes are hazards for which insurance coverage is available; consequently, models have been developed by commercial companies to support the insurance industry. Similar loss estimation models have not been developed for landslides because a) the geologists and engineers do not fully understand the insurance industry needs and b) no market exists for model output without insurance.

The development of a landslide model for insurance would seem to be more difficult and complex than the development of an earthquake or hurricane model. The actuarial issues in landslides are:

(1) Landslides are secondary events triggered by outside events but earthquakes and hurricanes are primary events.

(2) Landslides are not necessarily recurring events, whereas as earthquakes and hurricanes are.

(3) Given a triggering event (such as a rainstorm or earthquake), landslides may or may not actually occur. An on-site examination of every slope to develop accurate estimates of landslide likelihood would be difficult and expensive.

(4) Damage by landslides to buildings and land commonly is total, raising the catastrophe potential.

(5) Every model of any kind is based on the estimation of probability distributions of the essential predictive variables. It is not clear how these probability distributions can be established for landslides.

On the other hand, a landslide loss estimation model should be developed because:

(1) Landslides are common events, causing serious economic loss in many populated places worldwide.

(2) The growing population prefers to build on high ground with scenic views, often near cliffs or steeply sloping areas that may be prone to landslides.

(3) The local governments typically restore damaged land, roads and infrastructure at great cost.

(4) Many hilly areas have unfavorable geologic conditions which can result in landslides after heavy storms. Unfavorable conditions should be predictable, but buildings on sloping land may not be built correctly.

(5) Hillsides can be reinforced or modified to mitigate damage as a response to predicted vulnerability.

(6) The mechanics of landslides are understood.
(7) Areas susceptible to landslides can be mapped with geospatial systems that allow triggering events to be integrated.
(8) Ground movements can be detected when they are minor, possibly permitting mitigation measures to be implemented to reduce potential losses.

The socio-economic impact of landslides commonly is underestimated. Many landslides occur in response to other natural events such as rainstorms, floods, and earthquakes, so the economic impact usually is not considered separately. Hazard maps may incorporate landslide potential along with other slope processes, such as soil erosion, which is portrayed as unstable soil hazards. The distribution of damaged buildings may be noted on maps, but it is common for damage from multiple sources to be combined without identifying landslide as a cause.

4 DISCUSSION AND CONCLUSIONS

In the United States, general hazard maps issued by federal and state geological surveys depict incidence of past landslides or susceptibility of slopes to future landslide activity, as shown in Figure 1. It appears that landslide hazard maps in other countries may be similar. General hazard maps are insufficient for the insurance industry. Specific maps are needed which focus on potential landslide areas in terms that provide magnitude of slope movement and annualized frequency.

Specific large-scale earthquake fault maps are available for the public to use identify fault zone locations when purchasing houses in parts of the United States (California, Utah). Also, special requirements exist for building near fault zones. Even before computerized loss models were developed, fault maps were used by the insurance industry to control the amount of insurance issued near faults.

From the insurance industry perspective, detailed landslide maps would be useful to identify those areas where:
(1) The risk of a landslide is thought to be zero. In this case, the insurance company could issue an “all risk” policy covering anything that can happen, including ground movement.
(2) The risk of a landslide is thought to be equal to a 1-in-a-100 year event (annual frequency of 0.01). In this case, a limited number of policies could be issued in the areas with a premium surcharge for the landslide risk. Insurance would be available, but controlled.
(3) Landslides are likely to occur more frequently than once in 100 years. In these areas, private landslide insurance would not be issued at any price. In the future, effective mitigation measures would be required before insurance would be offered. In addition, modeling would be required to establish the appropriate premium level.

Actuaries rely heavily on statistics to model risk. In insurance, estimates are made of the frequency and severity of claims (e.g., automobile accidents). Usually, the frequency is modeled using a Poisson distribution and the severity is based on the log-normal distribution. The frequency and severity are assumed to be independent, which is usually true. In the case of natural hazards and catastrophes, they may not be independent: one large catastrophe can have both high frequency and predominately large severities.

Many usages and reasons exist for detailed landslide hazard maps to be developed. The point we try to make in this paper is that detailed landslide hazard maps are needed for the first step in the development of serious landslide models and for interesting the insurance industry to consider insuring landslides. The success of earthquake modeling can be emphasize with Figure 3 which displays the earthquake hazard in Spain and Portugal in exactly the same terms used in Figure 2 for the earthquake hazard in the United States. We prepared the map shown on Figure 3 in a few minutes using data readily available on the Internet (www.seismo.ethz.ch/GSHAP). Insurance companies can determine the earthquake hazard for a street address in Málaga, Spain, just as easily as for a street address in Memphis, USA. The building type, height, age, and use would be determined according to loss model input requirements.

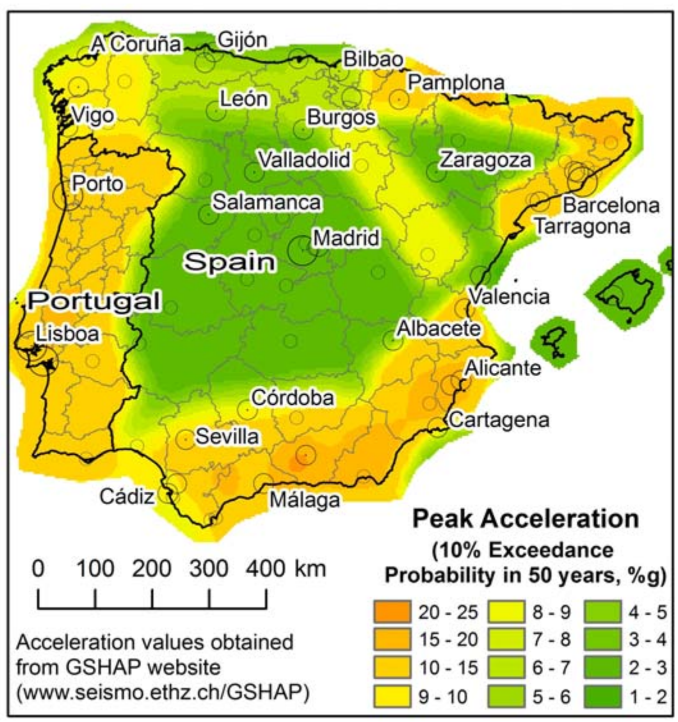

Figure 3. Earthquake hazard in Spain and Portugal.

Other relevant factors regarding landslide insurance include:

(1) Mitigation opportunities – the risk of landslides can be mitigated by landscaping, surface and subsurface drainage, and grading.

(2) Prevention opportunities –zoning and land use restrictions, slope stabilization earthwork.

(3) Liability for damage to neighboring properties – much more likely for landslides than in earthquakes; this becomes an important insurance-policy factor.

(4) Risk knowledge – without modeling, the property owner knows more about the landslide risk than the insurance company. With modeling the insurance company knows more than the property owner. Reverse adverse selection can exist – the property owner can actually overpay for landslide or earthquake insurance.

(5) Risk perception – people buy insurance based on their perception of risk, not the actual risk. This explains why people will buy earthquake insurance in areas where is little or no real risk of earthquake damage.

(6) Post-landslide economic recovery – insurance is always part of the economic recovery process. It is desirable because it efficiently and promptly pays needy property owners. It is much more efficient than government aid programs. Also, it is fairer in the sense than it is funded by a large group of people who were similarly at risk. Economic recovery is a huge problem after every kind of disaster.

Generalized comparisons between earthquake and landslide factors are tabulated below

Areal distribution	Earthquake damage is attenuated away from the source; sources are faults and seismic zones; local geology can amplify ground motion and produce ground displacements. Landslide damage is localized and controlled by geology and topography; damage is concentrated along differential deformation.
Temporal distribution	Earthquake damage occurs over a period that lasts less than minute. Landslide damage occurs over a period that can persist for days, weeks, months, or even years.
Process understanding	Earthquake processes are understood well for probabilistic models to be developed. Landslide processes are understood reasonably well at the individual slope level, but probabilistic models are limited to certain types of triggering events or processes.
Response understanding	Earthquake shaking stresses and deforms buildings in predictable ways depending on building structural systems; building contents behave in predictable ways. Landslide deformation stresses and deforms buildings in ways that depend on the location, orientation, and nature of deformation; building contents may be rescued from buildings damaged by slow movements.
Loss understanding	Earthquake losses result from building damage and function interruption at individual and community levels; infrastructure disruption, recovery operations, and repair; losses tend to be small to moderate percentage of building value. Landslide losses result from building damage and function interruption chiefly at an individual level; infrastructure disruption at a community level; recovery operations are localized; losses tend to be large percentage of building value.
Mitigation opportunity	Earthquake damage can be mitigated effectively with design and construction details; some site improvements may be useful to reduce ground displacements other than fault rupture. Landslide damage usually cannot be mitigated effectively with design and construction details; site improvements tend to be extensive and aimed at preventing slope movements rather than improving building response.

An approach that is similar to earthquake hazard mapping and risk assessment is needed for landslide hazard mapping and risk assessment. Analogues between earthquake hazard maps and landslide hazard maps were described by Perkins (1997); he recognized that landslide intensity required connections to variations in causes (magnitude and distance for earthquake-induced slides, rainfall amount and rate for rain-induced slides). He proposed that the landslide community consider developing probabilistic maps of landsliding caused by these two triggering processes to identify the probability that the threshold of slope movement might occur. Perkins (1997) believed that probabilistic maps of events that trigger landslides would be simpler to prepare than maps that depict the response of the slope to the triggering events. Perkins (1997) also recognized that procedures for defining landslide susceptibility were needed to permit estimation of the relative likelihood of landslide movement compared to some benchmark site conditions (topography, geology, groundwater). The landslide susceptibility information would allow useful distinctions to be made in relative hazard even though detailed quantification of the landslide mechanics may not be possible.

Perkins (1997) outlines the development of earthquake hazard maps in the United States. The initial seismic zone map in 1948 was based on the largest historical earthquake magnitude (energy released). The second hazard maps were produced in 1969 and depicted geographically smoothed Modified Mercalli Intensity (damage caused). The third hazard maps were developed in 1976 and depicted ground motion expected at a site with reference conditions regarding amplification or attenuation. Deviations from the reference site conditions were incorporated by adjustments to the results of a basic calculation. The basic calculation could be presented conveniently in probabilistic form as the map of ground motion corresponding to an exceedance probability of 10% in an exposure period of 50 years (the maps shown on Figures 2 and 3 for the United States and Spain and Portugal, respectively).

Perkins (1997) described four elements of a probabilistic earthquake-induced landslide intensity map:

(1) Geographic description of future earthquakes in terms of magnitude and corresponding annual rate.

(2) Definition of landslide intensity.

(3) Landslide intensity relative to earthquake magnitude and distance for a standard site condition.

(4) Definition of site susceptibility.

A probabilistic map of rainfall-induced landslides would require geographic description of rainfall amounts and corresponding annual rates. Landslide intensity definition is problematic; Perkins (1997) suggests that it could be landslide volume, run-out distance, or number of occurrences per unit area. This intensity definition is critically important for the needs of the insurance industry compared to the needs of emergency response officials. A large landslide mass that moves a small distance over a long period of time could substantially damage buildings and buried infrastructure (water, sewer), but pose little risk of injury or death to people.

Landslide risk mapping with geospatial tools, such as that described by Leroi (1997) and by Chung and Fabbri (2005), is a convenient technology that allows systematic analyses and mapping, and can be updated easily. Probabilistic landslide hazard maps appear to be more challenging to produce than probabilistic earthquake hazard maps because landslides are secondary processes triggered by primary events and standard site conditions have more components (slope steepness and curvature, orientation of geologic structure, hydraulic conductivity).

A need exists for probabilistic landslide hazard information in terms that are parallel to probabilistic earthquake hazard information. IAEG Commission No. 1, *Engineering Geological Characterisation and Visualisation*, is taking a systematic approach in an attempt to apply earthquake lessons to quantifying landslide occurrence and severity.

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