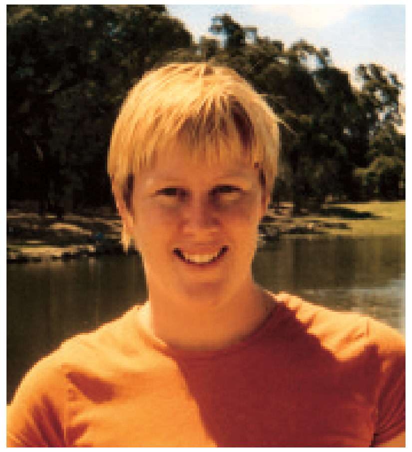
Christina Magill



Benfield (Australia) has recently funded a new position at Risk Frontiers to be known as *The Benfield Research Fellow on Volcanic Hazards.* As with most other work undertaken at Risk Frontiers, this position will have a strong insurance focus and it recognises that volcanic hazards have rarely been considered a serious threat to the industry. In some parts of the world, this cannot be taken with any surety: Japan, the Pacific North West of the US, Hawaii and Italy are just some areas where significant insured exposure lies within shooting distance of explosive volcanoes.

The first such Benfield Fellow is Christina Magill who recently completed her PhD on *Volcanic Risk in Auckland, New Zealand.*

Christina Magill was born in New Zealand and, after finishing high school vacillated between pursuing an interest in fine arts and earth sciences. In the end the latter proved stronger and, before moving to Sydney, she completed a BSc and MSc Hons in Earth Sciences at the University of Waikato. Christina's early research interests included physical oceanography and geology and her Masters thesis involved numerical modelling of tsunami generation.

In 2001 Christina began a PhD at Risk Frontiers where, under Professor Blong's tutelage, she turned her focus back to geological hazards. The result is a probabilistic volcanic loss model (*VolcaNZ*) for the Auckland Region that calculates exceedance loss statistics for damage to residential buildings as the result of volcanic ash falls. Ash falls arising from large distal volcanic centres in the central North Island, Taranaki and the local Auckland volcanic field are all considered. This work has been documented in a number of publications in international journals.

The Benfield fellowship will allow Christina to extend her PhD research over the next three years. This will include expanding the model to other cities and towns within the North Island of New Zealand and investigating likely damage to commercial and industrial buildings.

Longer-term implications of this work for the insurance industry are likely to be in other jurisdictions. Like the North Island of New Zealand, many other regions are at risk from multiple volcanic centres and hazards. Methodologies developed during this fellowship may be adapted to these regions and allow assessments of event losses from volcanic eruptions to be taken into account alongside windstorm and earthquake that have traditionally driven reinsurance pricing.

The next Risk Frontiers Seminar Series 2005 will be held on **Thursday 25th August, 2005** at the Museum of Sydney (Cnr Phillip & Bridge Streets, Sydney).

Presentations will begin at 2.30 through until 4.00pm with drinks and food to follow. Provisional speakers and topics include:

- Paul Somerville on "Earthquake Prediction"
- Andy Pitman on "Can land surface changes in the Sydney Basin affect storms?"
- Ryan Crompton on "Risk Frontiers' Australian Tropical Cyclone Model"
- John McAneney on "Cat Modelling: Are there objective criteria for judging models?"

Brokers: Bring your clients.

CORRIGENDUM

In the last Risk Frontiers Newsletter (Volume 4, Issue 3) Cyclone Tracy was wrongly reported as having destroyed Darwin in 1979. It was, of course, 1974.

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This Issue

Weak Ground Motions from Large Surface Faulting Earthquakes

The Benfield Research Fellow on Volcanic Hazards

SEMINAR ALERT
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Weak Ground Motions from Large Surface Faulting Earthquakes

In seismic hazard analyses, ground shaking level is assumed to depend on at least three variables: the magnitude of the earthquake, the distance of the site from the fault whose movement caused the earthquake, and the characteristics of the shallow geology at the site (e.g. soil or rock). It has always been assumed that ground shaking levels increase as the magnitude of the earthquake increases. The top part of Figure 1 shows a typical ground motion model that describes the decrease in peak acceleration as a function of closest distance to the fault for various crustal earthquake magnitudes. The peak acceleration increases with increasing magnitude in a systematic manner.

Until recently, there were few recordings close to crustal earthquakes having magnitudes larger than 7. The occurrence of several large crustal earthquakes in the past decade is starting to fill this data gap. Notable among these are the magnitude 7.6 Chi-chi, Taiwan, earthquake and the magnitude 7.4 Kocaeli, Turkey events, which both occurred in 1999, and the magnitude 7.8 Denali, Alaska earthquake that occurred in 2002. The strong ground motions recorded from these recent large earthquakes are inconsistent with the assumption that the ground motion level increases with magnitude. A preliminary ground motion model that incorporates the recent data is shown at the bottom of Figure 1. In this model, the ground motion level increases with increasing magnitude up to magnitude 7, and then decreases as the magnitude exceeds 7. This phenomenon, described further below, is termed "magnitude oversaturation."

Somerville (2003) and Kagawa et al. (2004) proposed that this unusual behavior is due to the fact that the ground motions of crustal earthquakes that produce surface faulting are systematically weaker than the ground motions of crustal earthquakes whose slip is confined to the subsurface. The large differences

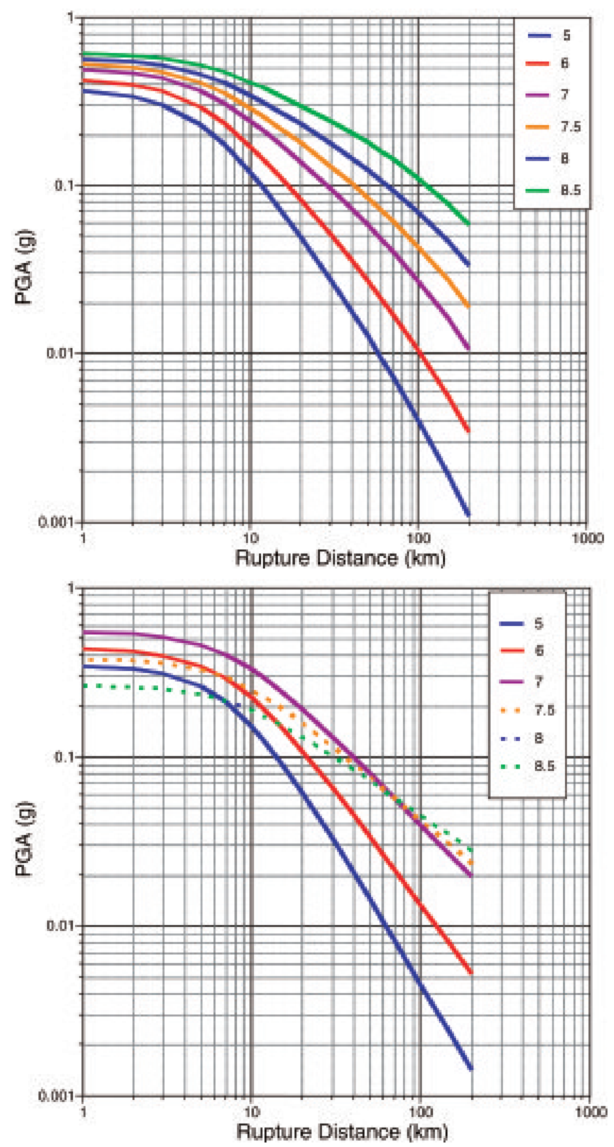

Figure 1. *Top: Conventional ground motion model in which peak acceleration increases with magnitude. Bottom: New ground motion model in which peak acceleration increases with magnitude up to Mw 7 and then decreases as the magnitude increases above Mw 7. Source: PEER-Lifelines NGA Project website.*

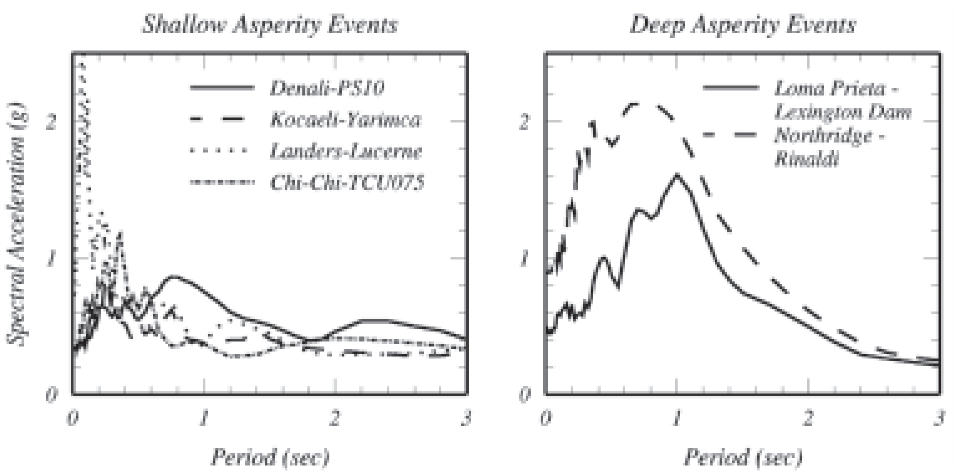

Figure 2. *Near-fault response spectra of recent large earthquakes. Left: Four earthquakes, Mw 7.2 to 7.9, with shallow asperities and large surface faulting. Right: Two earthquakes, Mw 6.7 and 7.0, with deep asperities and no surface faulting.*

in ground motion levels between these two categories of events are illustrated in Figure 2, which shows the response spectra of near-fault recordings of recent large earthquakes. The response spectrum, which is the method most commonly used to describe ground motions for engineering design and analysis, measures the maximum acceleration of the top of a simple representation of a building (a single degree of freedom oscillator) as a function of the natural period of vibration of the building (or oscillator). It is typical for a mid-rise building to have a natural period of about 1 second, and for a shorter building such as a house to have a natural period of a few tenths of a second. The left panel shows recordings from four shallow earthquakes in the Mw range of 7.4 to 7.9, and the right panel shows recordings from two deep earthquakes of magnitude Mw 6.7 and 7.0. The response spectra of the deep earthquakes are much stronger than those of the larger shallow earthquakes for periods less than 2 seconds.

The relative overall strength of the ground motions recorded from individual earthquakes is measured by the event term (Abrahamson and Silva, 1997), which represents the difference between the ground motions of an individual earthquake and those of the average earthquake of the same magnitude. The event terms for a set of surface rupture earthquakes are shown at the top of Figure 3, and for a set of subsurface rupture earthquakes at the bottom. The unity line represents the Abrahamson and Silva (1997) model, and lines above the unity line indicate that the event's ground motions on average exceed the model. The event terms of the 1999 Turkey and Taiwan events are represented by their residuals from the model. At periods between 0.3 and 3.0 seconds, the ground motions from earthquakes that produce large surface rupture are only about one-half as strong as those in which rupture is confined to the subsurface.

Why are the ground motions from surface faulting earthquakes weaker than for buried faulting earthquakes? At present, there is no definitive answer to this question, but there are some promising leads. Crustal earthquakes occur within the seismogenic part of the upper crust of the earth, which typically extends from the ground surface to a depth of about 20 km. Earthquakes typically initiate near the bottom of the seismogenic rupture zone in the crust, where its strength is at its maximum (Scholz, 2002). At depths greater than about 20 km, the crust is so hot that it tends to deform in a ductile mode in creep, rather than in the brittle mode that produces earthquakes.

Large earthquakes usually break the surface, but small earthquakes usually do not. Over one-half of the earthquakes in the magnitude range of 6.0 to 6.5 do not break the surface; this fraction decreases to about one-third for the magnitude range of 6.5 to 7, and about one-fifth of earthquakes in the magnitude range of 7.0 to 7.5. If it is assumed that all of the slip on a fault occurs during earthquakes, then this means that larger earthquakes are characterized by relatively larger amounts of shallow slip than are smaller earthquakes.

Why may these differences in the depth distribution of slip be important? Although the shallow events have large near-surface displacements, they do not have correspondingly large slip velocities. The slip velocities of the shallow events are about two-thirds those of the deep events. This causes the shallow events to have lower ground motion levels, because the slip velocity directly determines ground motion level.

What causes the slip velocity to be lower at shallow depths? We have already seen that the deeper part of the crust, in the depth range of about 5 to 20 km, is where the brittle failure that constitutes earthquake rupture begins. At depths shallower than 5 km, the fault is characterized, not by brittle failure, but by a low strength, strain hardening rheology. This zone may creep between earthquakes, and undergo slip at a reduced slip velocity during earthquakes, producing weak ground motions. The ductile, velocity-strengthening nature of the shallow part of the fault absorbs energy from the crack tip that propagates across the fault plane during the earthquake. This process may prevent all but the largest earthquakes from breaking the surface.

A large multi-year, multi-organizational applied research program called the Next Generation Attenuation (NGA) Project is now under way in the United States. In the initial phase of the project, which is nearing completion, five modeler groups are developing new ground models based mainly on an updated set of strong motion recordings of shallow crustal earthquakes in tectonically active regions. The weak ground motions recorded in recent large surface faulting earthquakes have lead to radical changes in the magnitude scaling of ground motions in some of these models.

In the previous generation of ground motion models, some modelers introduced "magnitude saturation" into their models. Magnitude saturation occurs when the ground

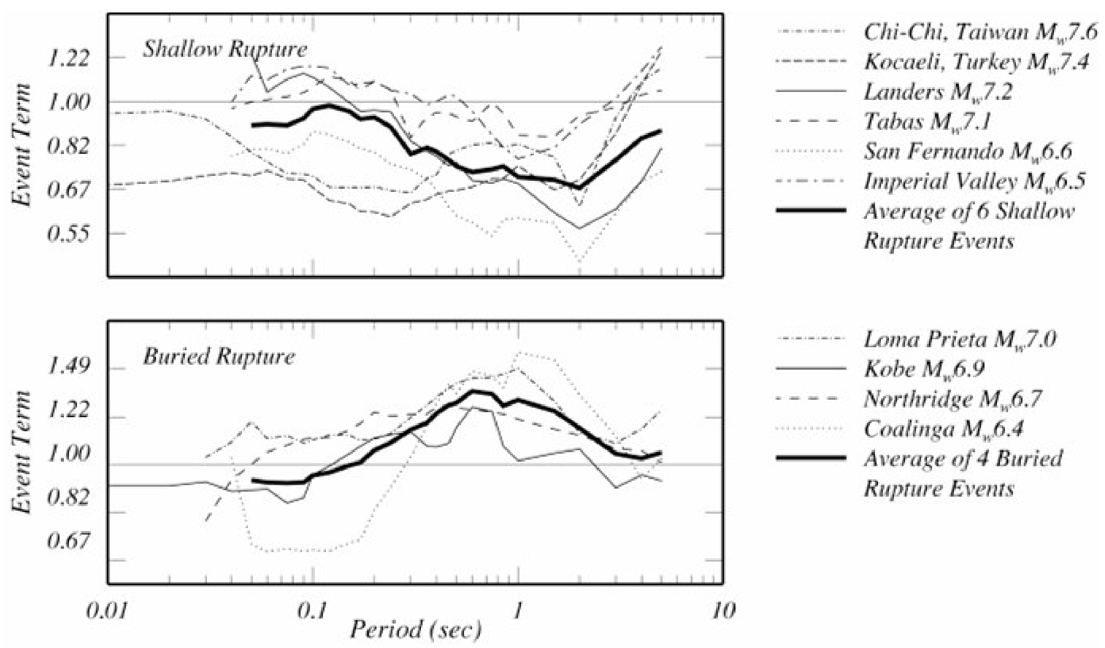

Figure 3. *Comparison of response spectral amplitude of individual earthquakes having surface rupture (top) and buried rupture (bottom), averaged over recording sites, with the amplitude of the average earthquake as represented by the model of Abrahamson and Silva (1997), represented by the unity line, which accounts for magnitude, closest distance and recording site category. The event terms (residuals) are shown as the ratio of the event to the model.*

motion level stops increasing as the magnitude increases. In some versions of the new NGA models that do not account for differences between surface and buried faulting earthquakes, there is "oversaturation," in which the ground motion level increases with magnitude up to a magnitude of about 7, and then decreases as the magnitude increases above 7, as shown at the bottom of Figure 1. It may be possible to avoid this severe magnitude oversaturation effect by developing separate ground motion models for surface and buried faulting. The model for buried faulting earthquakes is expected to show no signs of magnitude saturation, while the model for surface faulting earthquakes may reach saturation and may possibly oversaturate.

The utility organizations that sponsored the development of the NGA ground motion models are now faced with a complex predicament. Until recently, the ground motion levels in such models tended to increase after each major earthquake, as larger and larger ground motion levels were recorded. This caused some discomfort to the utility organizations, because it meant that older projects might no longer be designed to current standards, but accepting increases in ground motion levels always seemed prudent. Now, these utilities are contemplating accepting decreases in ground motion levels. Given their natural conservatism, this is causing even greater discomfort, and the utilities will need a lot of convincing before adopting these new models in engineering practice.

Does magnitude oversaturation of this kind apply in Australia? We do not have the data with which to definitively answer that question. In tectonically active regions like California, the shallow part of the crust is quite deformed from past faulting, and the shallow region of the fault is quite weak. In contrast, the tectonically stable crust of Australia may be less fractured and the shallow regions of fault may be stronger. This seems to be true in Western Australia and the Northern Territory, where earthquakes have recently produced surface faulting in very hard rock, in some cases apparently creating new faults, but it may be less true in southeastern Australia, which has undergone more tectonic deformation. So in Australia, especially in Western Australia and the Northern Territory, it is not clear that we would have the strain hardening behaviour in the shallow part of the fault that would give rise to magnitude saturation of ground motions.

What would be the impact in Australia if we did have magnitude saturation? The current probabilistic ground motion map of Australia assumes that earthquake magnitudes can be as large as 7.5, so adoption of over-saturation of magnitude scaling would tend to reduce the calculated seismic hazard level. However, earthquakes having magnitudes larger than 7 are so infrequent at a given location that their contribution to the probabilistic ground motion hazard becomes significant only for very long return periods. At the return period of about 500 years that applies to building codes, there might not be much impact. The impact might be mainly on dams, whose seismic design is based on earthquake scenarios that have very long return periods, and would tend to add a safety margin to those designs.

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