Risk assessment: providing an objective basis for risk management decisions

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ABSTRACT: The purpose of risk assessment is to provide information that will help risk managers make decisions. Organisations seek to identify risks to their operations and set policies in place to prevent adverse outcomes or to maximise possible opportunities. Management of earthquake risk falls into the former category: mitigation options usually address the possibilities of demolition, strengthening and insurance. But as in all areas of risk management, decisions become rather ad hoc unless they are based on objective assessments of risk.

The Regional Riskscape programme, undertaken by GNS and NIWA, seeks to provide assessment of risks across a variety of natural hazards. Earthquake risk assessments are now done routinely for insurance purposes, so that asset owners can make well-informed business decisions about the amount of cover they need, and negotiate structures of cover with insurance companies. Riskscape seeks to widen this expertise, not just for insurance purposes but also to aid risk managers in assessing mitigation options for a variety of hazards. These assessments need to be expressed in terms that are useful and meaningful.

1 INTRODUCTION

We have seen over the last few decades the development of seismic hazard assessment. It is now fairly routine to set up source models for point, line and area seismic sources, and to combine these with attenuation models to produce assessments of hazard that are specific to given locations. Source models take into account earthquake mechanisms and recurrence intervals for active faults, and strong motion attenuation functions incorporate site conditions. Future developments will no doubt include time-dependent aspects, as our understanding of the dynamics of the generation of earthquakes improves. But there is another development that is even more pressing: risk assessment.

Risk assessment goes one step further, to estimate likely losses to structures by modelling their vulnerability. This results in probabilistic estimates of losses, for specific portfolios of assets. Seismology has traditionally been close to the engineering profession, and this has resulted in the development of procedures for earthquake hazard assessment that are useful for engineering design, but it has not been as close to the insurance industry or to other risk management sectors so techniques for risk assessment are not so well developed.

Risk assessment is all about risk management. The only reason you do an assessment is because somebody has to make a risk management decision. An asset owner needs to decide how much insurance cover to purchase. An insurance company wants to know how much premium to charge. A city risk manager is faced with strengthening important buildings to protect against earthquake damage, and wonders what level of protection is appropriate. Or should he instead spend the money enhancing the city's flood protection system? Risk assessments can provide information to assist these risk managers in their decision-making, but the risk analyst needs to know the nature of the decision, and the constraints the decision-maker is working under, in order to express the results in the most helpful way.

2 RISK ASSESSMENT

The procedure for assessment of earthquake risk involves (a) modelling the exposure of all the assets of interest to all earthquakes that are likely to affect them, estimating the damage from each event, and (b) accumulating statistics of how often losses exceed a set of given values, expressing these losses in terms of a Loss Curve, also known as an EP curve (Exceedance Probability). An EP curve is shown schematically in Figure 1, in which the annual probability that any given level of loss will be equalled or exceeded drops from 1.0 for zero loss to 0.0 at the maximum loss than can occur. If a mitigation strategy is put in place, the curve changes by decreasing the estimated probabilities according to the effects of the mitigation strategy (broken line in Figure 1).

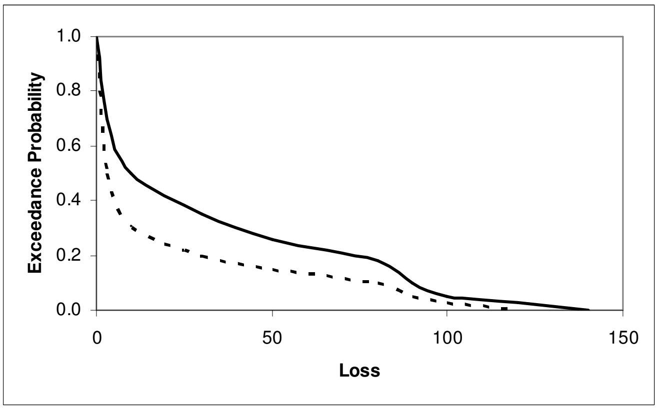

Figure 1. Schematic EP curves *P(x)*. The broken curve illustrates the reduction in risk through mitigation expenditure.

The task of the risk manager is to decide if the benefits of the mitigation strategy are worth the cost, so he needs a *measure* of the overall risk. One such measure is the Average Annual Loss (AAL), which turns out to be the integral under the EP curve. That is

$$E[x] = \int_0^\infty P(x)dx \tag{1}$$

We can also write this in terms of the inverse function *x(P),* by integrating along the probability axis.

$$E[x] = \int_0^1 x(P)dP \tag{2}$$

x(P) is always tractable because *P(x)* is a monotonically decreasing function. In this form the integral is more compatible with the further development in Equation (3) below.

But this is not a particularly useful measure for risk managers, as a discussion of insurance risk shows. When an insurance company writes domestic fire insurance policies, for instance, it wants to know the AAL because that will enable it to set premiums. Let's say it is $200 per year for houses like mine. But for me, as the purchaser of insurance, that figure is useless. I am more worried about the possibility of substantial loss, even total loss. So for the *seller* of insurance the AAL is a useful measure, but for the *buyer* it is not. I need other measures. I need to know the maximum loss that I am exposed to, the probability that it will occur, and the cost of protection against it. For catastrophe insurance, like earthquake, the situation becomes more complicated. Losses for fire insurance are largely uncorrelated, but this is not true for earthquake insurance because all policyholders claim at the same time. So in order to protect itself the company becomes the buyer as it purchases reinsurance; it needs other measures of the risk to its whole portfolio, because AAL is now not a useful measure. It needs to know how much it might lose, and with what probability. The reinsurance company, on the other hand, seeks to spread its risk by writing business internationally. The situation was nicely summarised by Kaplan & Garrick (1981): "A single number is not a big enough concept to communicate the idea of risk." And when we come to other ways of managing risk, the risk manager is like the buyer of insurance. The consequences of rare events are probably more important than the annualized loss.

Probable Maximum Loss (PML) is another measure that is used in the insurance industry, and this is relevant to the buyer. Unfortunately the adjective "probable" is often not well defined. Losses could go higher, depending on what is meant by "probable maximum".

Haimes (1998) has suggested the Conditional Expected Value as an alternative measure. This is the expected value of the loss, for those events whose probability of occurrence lies in a given range (or, equivalently, for losses in a given range). I have proposed (Smith 2004) that three measures be used to characterise changes in the EP curve: the 10-year event, 100-year event and 1000-year event. I define these as the conditional expected losses for events with annual probabilities in the ranges 0.032 to 0.32, 0.0032 to 0.032, 0.00032 to 0.0032, respectively. These limits are chosen because they represent the mid-points, on a log scale, of the intervals with central points 0.1, 0.01, 0.001. And unlike the AAL which is of limited value for the risk manager, these are rather like scenario events that can be readily envisaged. Together they represent the EP curve, and they can be derived from it readily.

It turns out that the Conditional Expected Value can also be determined from the EP curve, as:

$$E[x \mid P_1 < P < P_2] = \frac{\int_{P_1}^{P_2} x(P)dP}{P_2 - P_1} \qquad (3)$$

for events with annual probabilities between P_1 and P_2. Equation (3) is particularly appealing, because it may not be possible to determine *x(P)* at many points but the integration is still valid even if we are forced to interpolate between the computed values of *P* to produce a continuous function *x(P).* Figure 2 shows schematically the integration in Equation (3). A loss of x_1 or greater has annual probability P_1, and x_2 corresponds to P_2. The conditional expected value of the loss lies between x_2 and x_1. Note that Equation (2) is a special case of Equation (3), with P_1=0, P_2=1.

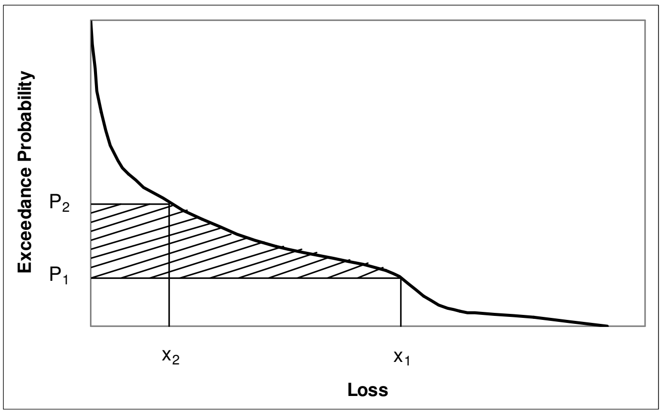

Figure 2. Schematic of the integration in Equation (3).

Several measures of the conditional expected value provide the risk manager with much more information than the AAL. The three proposed (10-year, 100-year, 1000-year) represent the entire EP curve in a way that the AAL and PML do not. Obviously the sequence could be extended to lower probability measures, and that may be necessary for situations of low probability and severe consequences, such as damage to large dams or nuclear power plants. But the three as proposed cover a wide range of applications.

3 REGIONAL RISKSCAPE

The Institute of Geological & Nuclear Sciences (GNS) and the National Institute for Water and Atmospheric Research (NIWA) have a 4-year joint research programme funded by the Foundation for Research, Sciences and Technology (FRST). This programme seeks to use existing knowledge about natural hazards to set up a modelling tool that will assist local and regional councils in their risk management. We have identified three areas for pilot studies: Buller, Christchurch City and Hawke's Bay, and will seek to model risks posed to assets in these areas by earthquakes, volcanoes, tsunamis, floods and storms. This will involve (a) setting up detailed asset databases for these areas, (b) modelling each hazard and the effects it has on those assets, (c) providing the means for risk managers to assess the benefits of various risk mitigation strategies. Because these hazards are modelled very differently, it will be necessary to find some common way of comparing the risk assessments, so that risk managers can assess priorities.

Risks posed by natural hazards vary significantly throughout the country. Flooding has been the major cause of damage during the past few decades, but some communities are affected much more severely than others. Earthquakes present a much more long-term threat, but that threat can be severe. So how will Regional Riskscape compare one risk with another?

3.1 Riskscape methodology

For earthquake risk assessment (e.g. Smith 2003), the procedures are established using MM intensity as a measure of ground motion and damage. This approach will be used in the interim while a spectral response engineering solution is developed for New Zealand. A synthetic earthquake catalogue, statistically consistent with the current New Zealand seismicity model of Stirling et al (2002) and its subsequent upgrades, will be constructed, and the damages estimated for all designated assets, as they are exposed to each event in this catalogue. Losses will be accumulated, and statistics kept, to produce the EP curve for earthquake.

For volcanic ash deposition, we have a program ASHFALL (Hurst & Smith 2004), which can be used to model the deposition of volcanic ash from an eruption, in terms of the volume and duration of the eruption, the height of the ash plume, the settling properties of the ash and the wind conditions prevailing at the time. A Monte Carlo approach, using the known or estimated eruption characteristics of each volcano and the recorded wind conditions at a variety of sites throughout New Zealand, provides ash thickness contours for the whole country as a function of mean return period. Eruption centres at Ruapehu, Taupo, Okataina and Taranaki are currently modelled, and others will soon be added. Damage as a function of ash thickness then needs to be modelled, and accumulated across the assets to produce the EP curve for volcano. The risk of damage from effects in the immediate vicinity of the volcano, such as pyroclastic flows and lava flows, are being ignored in the first instance.

Flood risk modelling is in its infancy, although damage from flood is more common than from any other natural hazard in New Zealand. Hydrological studies of catchments are well established, and can provide estimates of river flows at various return periods. We need initially to focus our modelling efforts on single catchments, and the effort will be in translating river flows (e.g. in cubic metres per second) to inundation heights at each affected location. Damage is critically dependent on inundation height: whether the water is above or below floor level makes a huge difference. To predict inundation height it is necessary to perform detailed flow modelling, with accurate ground elevation and ground roughness data. The result is a model of water depth and velocity. At a few selected return periods, then, we propose to estimate total damage, and this gives an EP curve represented only by a few data points. But the integration in Equation (3) is valid even if the data points are connected by interpolated values, so the conditional expected values of the damage can be determined. The assumption here is that, unlike earthquake risk, flood risk in a single catchment is likely to be well correlated among the various assets. It is therefore valid to use the hydrologically-determined return periods for river flow to estimate damage at those same return periods.

Tsunami risk will need to be treated in a similar way. There are models of the likely incidence of tsunami (probability and wave height) around the New Zealand coastline (UK Tsunami initiatives 2004). Inundation depth and water velocity estimates can be translated to damage estimates, and the tsunami EP curve developed as a series of points.

Storm risk should similarly be reasonably well correlated within a small region. Climatology studies provide estimates of return period as a function of storm severity. Engineering studies of the vulnerability of different types of buildings to strong winds will allow us to develop the EP curve for wind, as we accumulate damage across the various assets in the portfolio.

Many of these assumptions are necessarily simplifications. As modelling expertise develops, some of these may be able to be relaxed and more detailed modelling implemented.

3.2 **The goal is risk management**

The value of all this modelling comes when a risk manager wants to mitigate against natural hazards. First of all, the Riskscape modelling will identify where the largest sources of risk are. More importantly, though, it will allow examination of available strategies. Riskscape will be able to model not only the current situation but also some “What If?” scenarios. What is the benefit of mitigation work against earthquake, against flood, against volcano? For the last of these, probably not very much, in that it is difficult to protect against the deposition of volcanic ash. But for sensitive airconditioning systems, procedures for safeguarding air intakes may be a cost-effective measure. Strengthening structures against earthquake may be a cost-effective strategy in some locations, but maybe not in low seismicity regions such as Northland. The options are many as are the permutations.

The actual risk management decisions will be made by weighing up multiple criteria. Nothing will be simple, because as well as economic issues there will be social and no doubt political issues affecting the decisions. But however the decisions are made, the better the objective information that is supplied, and the more specific it is to the situation at hand, the better those decisions are likely to be.

4 **SUMMARY**

Objective assessments of risk are needed in order to make informed risk management decisions. Assessments need to be done to describe the existing risk and how it would change under proposed mitigation strategies. But a good measure of the risk is needed, and the simple annualised loss is not adequate for risk managers. The conditional expected value of the loss is a better measure, and it can be evaluated across a variety of hazards, even though the basic procedures for assessing risk differ.

The Regional Riskscape programme, a FRST-funded joint venture between GNS and NIWA, seeks initially to assess risk from earthquake, volcano, flood, storm and tsunami, to assets in three pilot areas, and develop a tool that will provide risk managers with useful measures of risk to assist their risk management decisions, including allocating resources across these five hazards.

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