Catastrophe Modelling

Catastrophe Modelling Working Party

Catastrophe Modelling working party 1999

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Abstract

This paper consists of two parts:

Part 1: Current developments in Catastrophe Modelling.

This part was written by George Walker of Aon, Syndey, Australia.

It is reprinted from Financial Risk Management for Natural Catastrophes (N.R.Britton & J.Oliver, Editors) published in 1997 by Aon Group Australia Ltd,Level 12 The Landmark, 345 George Street, Sydney, NSW 2000, Australia<www.aonre.com.au>. The paper was originally presented at the 1997 Aon ReAustralia Hazards Conference.

We have included it here as it gives a good background to the historical development of CAT modelling, and explains some of the potential uses of the output of CAT models.

We would like to thank George for allowing us to publish his paper here.

Part 2: DIY Catastrophe modelling

This part was written by the 1999 Catastrophe Modelling Working Party.

Although sophisticated CAT models are readily available there are many reasons why simpler methods are still required. This paper aims to provide some help to an actuary who is trying to make allowance for potential catastrophe losses without using a CAT model.

The Internet has been used extensively in researching this part of the paper and many suggested links are provided. In part this was done to illustrate what could be achieved using the Internet.

PART 1

CURRENT DEVELOPMENTS IN CATASTROPHE MODELLING

C.V. - George Walker

Dr George Walker is Executive Director - Strategic Developments, and a Director of the Aon Re Services Division, in Aon Re Australia. Prior to taking up his present position in 1994 he was for 5 years Assistant Chief of the CSIRO Division of Building and Construction, Sydney, and for 13 years before that Associate Professor of Civil Engineering at James Cook University of North Queensland, Townsville.

George is New Zealand born, and obtained his PhD in earthquake engineering from the University of Auckland in 1966. Following Cyclone Althea in 1971, which he experienced in Townsville, he extended his interests to wind engineering. He led the investigation of damage in Darwin from Cyclone Tracy and played a major role in the subsequent development of wind resistant housing standards in Australia. Other major disasters in which he was involved in the investigation of damage include Cyclones Eric and Nigel in Fiji, the Newcastle Earthquake, and Kobe earthquake, the latter as a member of the reconnaissance team from the New Zealand Society for Earthquake Engineering. He is the principal author of over 150 publications.

He is a past Chairman of the National Committee on Structural Engineering of The Institution of Engineers Australia, and of the Australian Wind Engineering Society. George currently chairs an International Standards Organisation Sub-Committee developing performance standards for housing, is an Australian representative on an APEC Task Group promoting the harmonisation of structural design standards in the Asia-Pacific region, and is a member of Australia's committee for the United Nation's International Decade for Natural Hazard Reduction (IDNDR).

His primary role in Aon Re Worldwide is to advise on the implications of the Information Revolution, particularly in relation to the use of complex computer models for risk assessment and financial risk management, and undertake related research and development activities.

CURRENT DEVELOPMENTS IN CATASTROPHE MODELLING

George R. Walker

ABSTRACT

As part of the impact of the information revolution on the insurance industry, GIS based catastrophe modelling is rapidly becoming an established tool for assessing of the risk of losses from extreme natural hazards, and the management of the risk. Changing from manual to electronic information processing is having dramatic effects on the economics of the insurance industry. One of the consequences is a move towards company wide integrated risk management and risk financing, including the development of portfolio management systems designed to maximise overall company performance by limiting accumulations and selectively pricing premiums based on individual policy risk. Catastrophe modelling is an essential requirement to do this where significant exposures to large losses occur. However, its use is far from universal, and even where it is used, it is often used in a very limited manner. This paper gives an indication of the current state of art of catastrophe modelling and sets out to improve understanding of the potential use of its output in maintaining a competitive edge in the emerging information age.

INTRODUCTION

We are currently living in revolutionary times in regard to information based services as society changes from manually processing information to processing it electronically using networked computer based systems (Toffler, 1990). This change can be compared with the industrial revolution when society changed from manually manufacturing goods and reliance on animal power and wind for transportation to using machines for these purposes. Powering the current revolution is the huge reduction in information processing costs which is changing the whole economics of commerce. This is coupled with opportunities for radically new approaches to commercial activities which are being made possible by these changes.

The insurance industry is typical of information based industries which are being dramatically affected by this information revolution (Dlugolecki, 1995). The frequent news items of mergers and staff redundancies are the most public signs of the impact of this revolution. The latter in particular are often the result of using the new technology to do the same things more efficiently, which is always the first reaction to a new technology. The mergers however are increasingly the result of the radically new approaches to managing and conducting business that the information revolution is making possible (Mahoney, 1995). It is these developments which are producing the revolution.

The information revolution is having five main impacts on business operations.

1) It is rendering obsolete the traditional line structure of management and replacing it with a more amorphous structure in which all can directly communicate easily with each other, and input their expertise directly where it is required, rather than indirectly through hierarchical structures. This may be described as the *communication* impact.

2) It is replacing the manual recording, analysing, storing, moving and retrieving of information which has been the core of most commercial transactions by electronic systems. This may be described as the *information processing* impact.

3) It is leading to integration of activities directed towards a common purpose within organisations and between organisations, due to computer systems not being limited to the knowledge and expertise of a single human mind. This may be described as the *integration* impact.

4) It is leading to commercial services customised to the individual customer's needs, as opposed to uniform mass produced services, as a result of the power of computer systems using large databases to discriminate at the individual level at point of sale. This may be described as the *customisation* impact.

5) It is leading to the creation of a global village in relation to the trading of products and services, as a result of the dramatic reductions in the cost of

developing and maintaining long supply lines. This may be described as the *globalisation* impact.

The insurance industry as a whole will undergo dramatic changes in the next few years as a result of these impacts. Some parts of the industry are already experiencing the consequences of some of these changes. One of these is a move towards company wide integrated risk management and risk financing. This development within many large corporations has already led to major changes in the way they insure themselves such as the development of in-house captives. Now insurance and reinsurance companies are starting to apply the same techniques to their own operations. A consequence of this is the development of integrated portfolio management systems designed to maximise overall company performance, and customised pricing of premiums based on individual policy risk.

In the property insurance field geographic information systems (GIS) based catastrophe modelling is being developed as part of this overall system of integrated financial risk management where there is a significant exposure to the risk of catastrophe losses.

TRADITIONAL APPROACH

The traditional approach to insuring against catastrophe losses has been to regard it as similar to fire insurance, either by including it as part of the standard property insurance policy, or offering it as an optional extension to such a policy. A blanket approach tended to be adopted based on the perceived risk of occurrence of the hazard regionally or nationally without respect for individual mitigating or extenuating circumstances. In Australia flood was perceived as uninsurable in respect of household and small business insurance, and was largely excluded. Apart from Adelaide, after 1954, and Perth, after 1969, earthquake was not considered a risk and insurance against it was effectively provided free. Until Cyclone Althea in 1971 and Cyclone Tracy in 1974 wind losses were regarded as similar in nature to fire losses and reasonably predictable with their contribution to premiums being based on experience over the previous few years.

Cyclone Althea to a limited extent, and Cyclone Tracy much more forcibly, highlighted to the Australian insurance industry that a major difference between fire insurance and catastrophe insurance is the effect of accumulation. To accommodate this the insurance industry introduced the concept of catastrophe zones which, because they were standardised by the Insurance Council of Australia (ICA), are known as the ICA Risk Zones (Insurance Council of Australia, 1990). By multiplying the portfolio accumulation of insured value in each zone by an appropriate percentage, an insurance company was able to estimate its probable maximum loss (PML) from a single event in each ICA Risk Zone (Allison, 1983). The 'appropriate percentage' used in each zone tended to be a consensus figure based on past experience and professional opinion. The largest zone PML was then used as the basis for determining the upper limit of possible loss for reinsurance purposes. The distribution of zone PML's was used by the lead reinsurers in determining the rates for the different layers of cover.

The contribution of catastrophe risk to individual premiums was then based on the cost of reinsurance plus the regular losses covered by the retentions. Because the zone PML's were for all hazards, and the portfolios were treated in aggregate, not individually, the resultant catastrophe contributions to premium rates were blanket rates which did not distinguish between hazards or take account of individual vulnerability. The disincentive that this blanket approach had on mitigation has been discussed by the author elsewhere (Walker, 1995, 1996).

It was a system designed for a precomputer age when the costs of undertaking a more detailed analysis were perceived as unjustifiable at a time when reinsurance rates were relatively cheap. In the environment in which it was developed this approach served the industry well, with reinsurers and insurers alike developing systems to handle it in an effective manner. However the system relied heavily on empirical opinion based on a perception of likely loss derived from previous experience. It did not take into account differences in vulnerability between portfolios, and assumed all loss from any single event occurred in a single zone. In determining their maximum PML's, companies sometimes included some consideration of the latter two factors, but again on an empirical subjective basis. Where the risks and uncertainties were well recognised the percentages were probably often conservative, but where risks were poorly perceived the approach could result in significant underestimation of the real risk.

As a tool for modern integrated financial risk management this approach is totally inadequate.

DEVELOPMENT OF CATASTROPHE LOSS MODELLING

Modern catastrophe loss modelling is largely derived from two developments which began in the 1970's. One of these was spatial modelling of physical characteristics of extreme natural hazard events on computers. The other was spatial modelling of insurance loss for a given areal distribution of hazard.

Prior to the 1970's structural engineering designers used nominal design wind speeds and earthquake accelerations which, like ICA Zone PML percentages, were consensus figures based on past experience and the opinion of specialists in these fields. Structural engineers were among the first to recognise the value of computers, and used them to refine structural design by simulating structural behaviour under loads on the computer. This led to the need for probabilistic modelling of loads, including those due to wind and earthquake. While reasonably good information was available on the characteristics of past tropical cyclones and earthquakes, recorded data at specific locations on wind speeds and earthquake intensities during them was poor. To use the available data to best effect it was necessary to model the events themselves to produce the spatial distribution of wind speeds and earthquake intensities. Then, by using the knowledge on the frequency of occurrence of tropical cyclones and earthquakes in particular regions, return periods were derived for different levels of wind speed and earthquake intensity for individual localities. In Australia such models were developed for tropical cyclones in the wake of Cyclone Tracy (Gomes and Vickery,1976; Martin and Bubb, 1976) based on a procedure developed by Russell (1970). Since 1975 design wind speeds for cyclone areas in the Australian wind code (Standards Australia, 1989) have been based on results from these models. Similarly, the design earthquake ground accelerations in the current Australian earthquake code (Standards Australia, 1993) are based on corresponding earthquake modelling (Gaull, Michael-Leiba and Rynn, 1990).

Concurrent with this development in the structural engineering field, but independent of it, during the 1970's Dr Don Friedman at the then Travellers Insurance Company in the USA applied his knowledge of typical distributions of wind speeds in past hurricanes, and ground motion intensities in past earthquakes, to estimate insurance losses that could occur in different major centres of population if these distributions were superimposed on them (Friedman, 1975). He used knowledge of losses obtained by his company in past events for which estimates of the spatial distribution of wind speeds or ground motion intensities were available. Friedman achieved this by mapping the portfolio of property risks on a computer and superimposing the postulated distributions of wind speeds (or earthquake intensities) on these and integrating this information with the assumed vulnerability information to obtain estimates of total losses. These studies were the origin of modern catastrophe modelling.

These two developments came together towards the end of the 1970's when engineers who had developed probabilistic hazard models realised they could be combined with the Friedman deterministic loss models to produce probabilistic catastrophe loss models. At James Cook University of North Queensland a probabilistic GIS model of tropical cyclones had been developed in the late 1970's to study the risk of storm surge for engineering design and emergency planning purposes (Sobey, Harper and Stark, 1977). Following a US - Australia workshop on coping with tropical cyclones held in Townsville in 1980 which was attended by Friedman, the late Professor Stark and the author developed a proposal for establishing a Centre at James Cook University to develop integrated cyclone impact models for coastal communities in Queensland based on a combination of the two developments (Stark, 1980). Unfortunately it was ahead of its time and received no support. It is only in the last couple of years that such a project has got off the ground in Australia with the creation of the Australian Geological Services Organisation (AGSO) Cities Project (Granger,1996). In the USA, Dr Harish Shah of the Department of Civil Engineering at Stanford University was having similar ideas in regard to the application of probabilistic earthquake models. He was more successful in gaining support resulting in the development of IRAS, the Insurance Risk Assessment System (Dong, Wong, Kim and Shah, 1988). The commercialisation of this model gave rise to Risk Management Solutions Inc (RMS), one of the leading companies specialising in catastrophe risk modelling.

Despite warnings based on these models from Friedman and others that the insurance industry was at much greater risk from catastrophe losses than was generally realised (All-Industry Research Advisory Council, 1986), the insurance industry did not take a great deal of interest in catastrophe modelling until the 1990's.. The ready availability of reinsurance at relatively low rates and a twenty year history of low losses were major contributors to this attitude.

This attitude changed dramatically in the early 1990's as a result of the sequence of large world wide catastrophe losses that began in 1989 and peaked with Hurricane

Andrew in 1992. World-wide, there was sudden shortage of reinsurance capacity to meet the new perceptions of PML's, making it more difficult to obtain reinsurance and leading to big increases in reinsurance rates. These increases in rates encouraged new players into the reinsurance market, particularly in Bermuda where a benign tax regime favoured this development. In the USA, where the biggest losses occurred, insurance companies responded by trying to withdraw from known hazardous areas or raising rates, but found difficulty in doing so because of the tight control of the insurance industry by regulators. These consequences created a demand for the new catastrophe modelling tool. Because of the higher ruling reinsurance rates, companies wanted to get a better estimate of their PML's and found reinsurers more receptive if modelling had been undertaken. The new reinsurance companies in Bermuda needed the improved estimation of liabilities that catastrophe modelling offered, to satisfy themselves and their clients of their solvency. Meanwhile in the USA companies found that without catastrophe modelling it was difficult to convince regulators to allow them to change their prices and conditions.

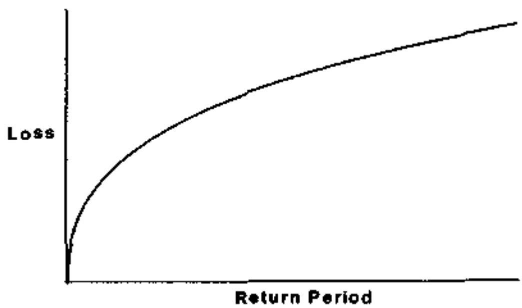
This created a rapidly increasing demand for catastrophe modelling services, especially in the USA. Initially there were only three significant providers of these services, each of them companies that had been developing the technology during the 1980's. These were RMS, EQE and Applied Insurance Research (AIR). Others, however, soon saw opportunities in this rapidly expanding market. As a result the last few years has seen a proliferation of companies offering catastrophe modelling services, including major reinsurance brokers and reinsurance companies, actuarial consultants and specialist engineering consultants. Most of this activity is occurring in the USA where the major demand has been for these services, but it is also happening in the UK, Europe, Australia and New Zealand. The models vary in sophistication depending on the primary end user, with the more general models being more acceptable to reinsurers, and the most detailed ones being more acceptable to corporate companies requiring single site analysis of specific facilities.

Coverage geographically by hazard is still limited. As most of the effort has been directed at the USA market, the best coverage is to be found there, where models of some form are available for most of the major hazards nation wide. For major events, such as hurricanes and earthquakes, there are many models now available. Most of them appear to be directed at particular niche markets, not all of which are related to insurance. For other hazards, such as tornadoes and hail, the number of models available is much more limited. Outside the USA wind and earthquake models are the most common, but the regions for which such models are available is still quite limited, and potential users often have very little choice of provider when they are available.

Although overall their use in Australia has been relatively small, some Australian companies were among the pioneers in using them. These companies began using the New Zealand based Works Consultancy earthquake modelling services in about 1990. Since then at least four tropical cyclone models and two earthquake models have been developed within Australia to meet anticipated needs, and to provide some competition to the international providers of these services. To date, however, most of them have not been greatly utilised. Despite the soft market for reinsurance, their use in Australia is nevertheless on the increase. Until now they have been primarily seen as an alternative to the traditional ICA Risk Zone accumulation approach of estimating PML's for reinsurance purposes. The revolutionary aspect of catastrophe modelling in the contribution it can make to changing the way insurance businesses are managed is just beginning to be appreciated.

UTILISING THE OUTPUT

Figure 1 Typical Form of Output from Catastrophe Loss Model



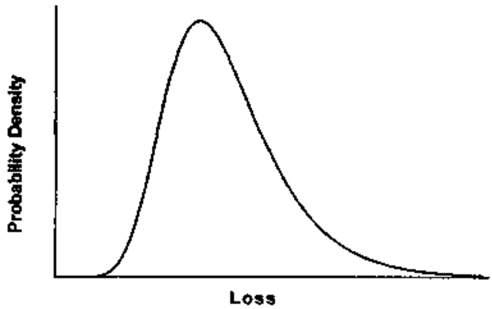
The primary output from a catastrophe loss model is a loss-probability curve. This is normally in the form of loss versus return period, as shown in Figure 1, where the return period is the inverse of the probability of occurrence in one year. The loss may be the loss experienced by a single property or facility (single site analysis), the aggregate portfolio loss in a particular catastrophe zone (zone analysis), or the aggregate portfolio loss for a whole state or country, or world wide (geographically integrated analysis), from a particular hazard (specific hazard analysis) or all hazards (multi-hazard analysis).

A fully integrated corporate risk management program would require output at all these levels. For overall management of the corporate balance sheet the risk profile for the total worldwide portfolio for all hazards is the most relevant. For purchasing reinsurance or other forms of financial protection, regional or country risk profiles will be needed. For internal management of risk, the state or country risk profiles will be needed. Finally for individual rating purposes a combination of single site analyses and zone analyses for specific hazards to determine their specific contribution to the overall cost of financial protection will be needed.

The use of captives by an increasing number of large corporations is a response to an integrated approach to risk management. To date, although it is having a significant impact on their own business, insurance companies have in general not been part of this trend. However this situation is not likely to last for long as the competitive advantages of adopting an integrated approach become apparent.

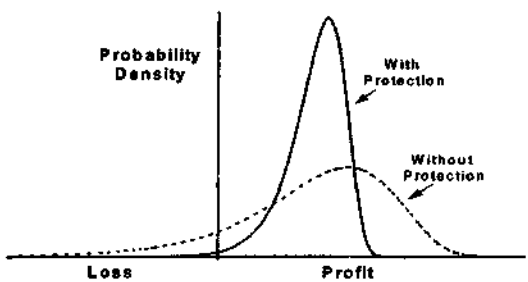
The loss profile shown in figure 1 is in the form of a cumulative probability curve. The points on the curve represent probabilities of exceedance of the indicated value of the loss (not the probability that the loss will equal the value which is often mistakenly assumed by those unfamiliar with statistics). That is, if for a 500 year return period a loss of $100 million is indicated, this means that there is a probability of 1 in 500 that the loss will exceed $100 million in the twelve month period for which the exercise is being undertaken.

Figure 2 Loss Profile as Probability Density Diagram



Loss profiles can also be transformed into probability density or frequency diagrams which are more useful for describing how the output of catastrophe loss models can be used for integrated risk management. Figure 2 shows a typical loss profile plotted in this form. This can be combined with the corresponding probability curve for expected earnings exclusive of any financial protection costs over the corresponding twelve month period to obtain the probable net worth without protection as shown in the dotted line in figure 3. The objective of integrated risk management is to design a system of financial protection which optimises the expected net earnings including the cost of financial protection, in terms of company's own risk culture, as shown in the full line in figure 3 (Coutts and Thomas, 1997; Walker, 1997).

Figure 3 Expected Net Earnings With and Without Financial Protection



In purchasing insurance or reinsurance a starting point for rationally analysing rates is the *burning cost*, which is the average or mean expected loss. For commonly occurring losses like fire and theft it is usually possible to get a good estimate of the burning cost from the past few year's losses. For catastrophe losses this is not possible, and until the advent of catastrophe modelling, the determination of rates for catastrophe insurance was largely empirical. However it is a relatively simple mathematical exercise to obtain the burning cost from the loss profile as shown in figure 1. In this form the burning cost is given by the following equation:

$$BurningCost = \int \frac{dL}{T}$$

The burning cost can be evaluated for the whole cost profile, or as is more commonly required for reinsurance, for different ranges of loss as shown in Figure 4 and Table 1.

Figure 4 Typical Approach to Reinsurance

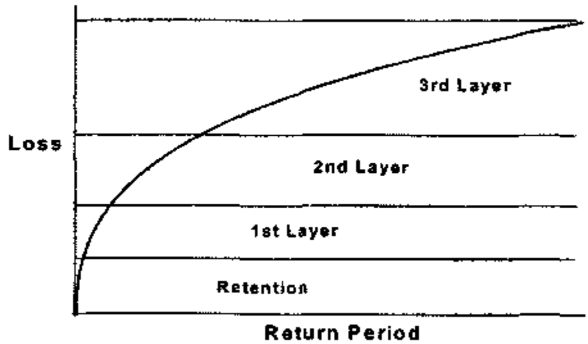


Table 1 Evaluation of Pure Rates on Line from Loss profile

Layer	Loss	Burning Cost	Pure Rate on Line
Retention	$20M	$14M	70 %
1st 30M XS 20M	$30M	$3M	10 %
2nd 50M XS 50M	$50M	$2M	4 %
3rd 100M XS 100M	$100M	$1M	1 %

Table 1 also demonstrates how, by dividing the burning cost for each layer by the range of loss in each layer, the pure or technical rate on line for each layer is obtained. This is the premium rate which would need to be charged to meet the losses only and just break even in the long term. Actual rates on line would normally exceed this to account for administration costs, profit and the cost of providing for the availability of capital to meet large losses with low probabilities of occurrence. Generally, the ratio of the actual rate on line to the pure rate on line increases with return period.

The rating of individual insured risks will be a function of their overall burning rates and their contribution to accumulations of catastrophe losses for which financial protection is purchased. In small isolated communities the ratings will largely reflect the burning costs only. In large communities the accumulation factor may have a large multiplying effect on the burning costs. Evaluation of ratings therefore needs the loss profile for both single site analysis and for the accumulations to which it contributes, as well as information on how these accumulations affect the overall risk profile for which financial protection is provided.

The processes for utilising the results of catastrophe modelling are complex and not amenable to manual analysis. They have only been made possible by the power of computers to undertake such analysis, and to do it relatively cheaply. The mathematical techniques involved are relatively straightforward but much tedious computation is required. The limits on their use are not the techniques or computing power. They are more related to human conservativeness in the face of technological change, and the cultural problem of an industry which has historically depended on investing in human resources which are almost instantaneously productive rather than investing in capital resources such as machinery or complex computer systems where there may be a considerable delay between the investment and the return. As a result most of the industry is still trying to pour the new wine into the old wine skins. Many of the issues that concern the industry about catastrophe modelling are a consequence of this. Some of these and the associated misconceptions will now be discussed.

SOME CURRENT ISSUES AND MISCONCEPTIONS

Interpretation of Loss Profiles

Some of the problems the industry has with catastrophe loss modelling arises from misconceptions about the interpretation of the loss profile information. These occur in respect of both the loss and return period or probability. The latter is the more significant.

The most common way in which loss profiles are presented is in terms of the estimated loss for events with varying return periods. There are two contributing factors to the uncertainty of the losses to be expected in a given year: scientific uncertainty and human uncertainty. Scientific uncertainty refers to the randomness of the natural processes that give rise to the extreme events producing catastrophic losses. This uncertainty is simulated in the catastrophe models and calculations made of the losses arising from them. However, because of limited human knowledge, the true values of the factors used in simulating the scientific uncertainty, as well as the resulting hazard characteristics and the losses arising from them, are unknown, and only estimates based on known knowledge are used. The uncertainty this introduces can be described as human uncertainty.

To account for human uncertainty it is common to present results in terms of confidence limits. Thus instead of a single loss profile, two or more loss curves may be produced. Typically, these might be the expected loss and the 90 percent confidence limit loss. Strictly speaking these are curves of conditional probability. The expected loss curve gives the most likely value of loss that will occur, given an event with the specified return period. This loss has approximately a 50 percent probability of being exceeded, and therefore in absolute probability terms corresponds to a return period of twice the specified return period. The 90 percent confidence limit curve gives the value of loss that has a 10 percent probability of being exceeded given the specified return period, and therefore in absolute probability terms corresponds to a return period of ten times the specified return period.

It can be shown that if the human uncertainty is small the expected curve is a reasonable, and generally conservative, approximation of the absolute probability curve. If the human uncertainty is large this may not be so and the absolute probability curve should be derived from the conditional probability curves. (If the 90 percent confidence value for a particular event return period is greater than the expected value for 10 times this return period, or the 80 percent confidence value for a particular event return period is greater than the expected value for five times this return period then the human uncertainty is large.) However to use the event return period corresponding to the 80 or 90 percent confidence limit value as indicative of the true probability that this loss will be exceeded can be very conservative.

The loss may be either the total annual loss, or the loss from a single event. Since traditional PML estimates were based on single events, and reinsurance is generally negotiated in terms of a single event, this is the output that is probably most commonly requested. However, the total annual loss is in many ways the more important figure, especially when portfolios are well dispersed geographically and at risk from a number of hazards. Catastrophe models can produce both sets of information, and both should be requested so that comparison can be made between reinsuring against events as opposed to reinsuring against total annual losses. Where reinsurance is obtained on a single event basis, information should be obtained on the probability associated with subsequent losses as an aid to negotiating reinstatement premiums.

PML Return Periods

One of the commonest questions asked about the output from catastrophe modelling is what return period should be used. It appears to be a major concern for both insurers and regulators. The question is asked in respect of the determination of the PML for reinsurance purposes, and most commonly in respect of a single accumulation zone for a particular hazard. It is the most obvious sign that within the insurance industry there is a widespread lack of appreciation of the real significance of catastrophe modelling. Behind the question is an assumption that there is a unique answer. There is not. The significance of catastrophe modelling is that it presents the exposure of a company to catastrophe risk in probabilistic terms across the full range of return periods. To ignore all the curve except one point is to waste most of the value of doing the exercise.

For any particular company the cut-off value for providing financial protection should depend on a wide range of factors including the shape of the curve, the geographical extent of their portfolio, the full range of hazards to which it is exposed, the overall financial strength of the company as reflected by its balance sheet, and the cost of financial protection.

Figure 5 Different Loss Profile Shapes

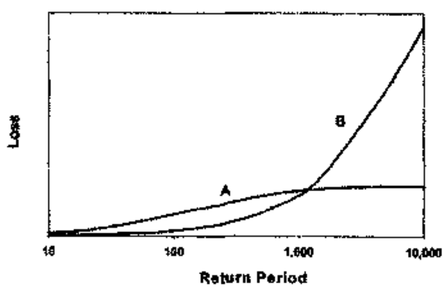
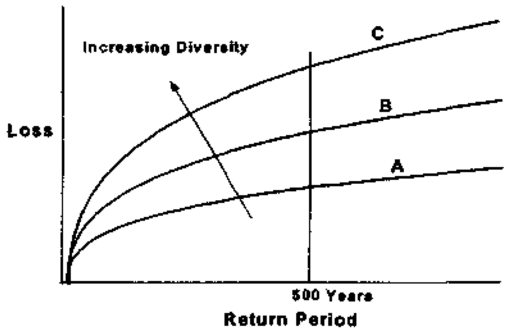


Figure 5 demonstrates two different shapes of possible loss profiles. At the 200 to 500 year return period, curve A indicates losses of the order of twice those of curve B, but at more extreme probabilities curve B indicates losses of several times those of curve A and many times the indicated losses at a return period of 500 years. If curve

A is typical of the loss profile for a company then may be 500 years is an appropriate upper limit. If the loss profile is more like curve B then it may not be, especially if at the extreme return periods the loss could bankrupt the company. This argument is particular relevant to Australia as in intraplate earthquake regions like Australia loss profiles for earthquakes will be much more like B than A.

Figure 6 Effect of Geographical and Hazard Diversity on Loss Profiles



The effect of diversity of geography and hazard on the appropriate return period, if based on a single zone and single hazard, is demonstrated in figure 6. Suppose curve A is the loss profile giving the largest loss at a return period of 500 years at accumulation zone level for any single hazard. If almost all of the company's exposure is in this zone and there is only a significant risk from this hazard then this will closely approximate the integrated loss profile for the company's whole portfolio for all losses. In this case the indicated 500 year loss will closely approximate the real 500 year risk of loss to the company. On the other hand if the company has a number of accumulations at significant risk from a number of hazards then curve B or C may be more representative of the risk to the whole portfolio. In this case the maximum 500 year loss based on single accumulation zones and single hazards can seriously underestimate the real 500 year risk of loss to the company. This highlights a fallacy of much of the current debate on appropriate return periods.

The cost of financial protection will also affect the optimum value of the upper cut-off level for financial protection. When it is cheap the optimum upper cut-off of return period will be higher than when it is expensive.

Quality of Models

A common concern raised about catastrophe models is the quality of the modelling embodied in them. To most users of the models they are black boxes of which they have little or no understanding. Nor is it generally possible to obtain from the suppliers the detailed knowledge of the workings of the models and the assumptions used which is required in order to make an assessment of their quality. Reports of different models giving widely differing answers does nothing to allay these concerns. In the United States and Bermuda it is indeed quite common for insurance and reinsurance companies to analyse their portfolios with several different models rather than be dependent on one (Cloney, 1997).

It needs to be remembered that computer software systems such as catastrophe loss models are the information age equivalent of machines in the industrial age. Relative to today's standards the early examples of the latter were not of a very high quality. The catastrophe models available today are the equivalent of the early machines. Currently their quality is not high, but it is improving all the time. But like their industrial age equivalents they still represent a step change from what was previously available. The step change is not in their ability to provide a single estimate of the probable maximum loss in a particular city due to a particular hazard. They have only provided a marginal change to these estimates. Rather, the step change is in their ability to provide an indication of the total loss profile over all return periods for all hazards for the complete portfolio or any portion of it. That is in their ability to provide a three dimensional picture of the risk instead of the one dimensional single point estimate used previously. Only with this information is it possible to include catastrophe losses in an integrated approach to financial risk management. Uncertainties there may be, but the techniques allow these to be taken into account in a rational manner. The reduction of these with time will correspond to the improvement in efficiencies of machines with time, but their presence is not an argument for not using catastrophe modelling.

There is a need however for some form of quality assurance scheme to be introduced which would enable users to distinguish between say a 5 star model and a 3 star model. This will require standards to be formulated against which the different models can be benchmarked by independent assessors. Such standards will be required for all the different models which the industry will find itself needing to use, not just catastrophe models. It is a task which the insurance industry as a whole at the international level should be tackling.

Cost

Another issue in the insurance industry is the costs of undertaking catastrophe loss modelling. Whereas previously it was a case of working out the accumulations in each zone and multiplying these by a well established percentage PML figure, an exercise that might take one person no more than a day using spreadsheets, catastrophe modelling may cost hundreds of thousands of dollars and take several months to get the answers. If only a single zone single hazard loss for a specified return period is sought, and this does not come out significantly less than the previous answer - and there is no guarantee that it will - then many users feel the whole exercise has not been worth it. If this is all it is being used for then they are right.

The value of undertaking catastrophe modelling lies in the step change described above in the information it provides on the nature of the risk, not the marginal improvement in a single point calculation. To do this requires a complex computer software system that is expensive to develop and maintain. Like machines in the manufacturing and transport industries these require an up-front investment that may appear expensive. The benefits lie in the overall savings arising from an integrated approach to risk management, and the increased competitive marketing opportunities, which this investment makes possible.

CONCLUDING COMMENTS

In the words of Cloney (1997) 'Models are here to stay'. They are an inherent part of the revolution in information technology that is sweeping the world, especially service industries like the insurance industry. Catastrophe loss models are not an end in themselves but a means to an end. This end is an integrated approach to risk management that incorporates all risks to the financial well being of a company.

Catastrophe modelling can only provide marginal benefits to companies whose only interest in them is in obtaining a better estimate of their PML's for use in the traditional manner. It will be much more effectively utilised when it is recognised as a necessary subset of more extensive financial risk models used to optimise companies' profitability in an integrated manner. This approach will require a change in culture for an industry which has no history of investment in the future. It is a change which characterised the early industrialists who exploited the opportunities of the industrial revolution by investing in factories and machinery - something we now take for granted in respect of manufacturing. It is a change that will probably characterise the successful insurance companies in the 21st century. For them, catastrophe modelling will be just a routine operation.

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PART 2
DIY CATASTROPHE MODELLING

Abstract

Despite the advances made in Catastrophe modelling in the past decade, there are still many reasons why an actuary cannot rely on the sophisticated CAT models for all tasks connected with the quantification of the potential impact of catastrophes.

In this paper we discuss the type of models that may be built in-house. These range from the simplest possible to a model which aims to mimic the workings of the CAT models.

We have used the Internet extensively in researching this paper. We provide many links to web sites that the reader may find useful. We aimed to illustrate how the use of the Internet makes it possible for an actuary to access the work of the scientific community. However, care should be taken when using the Internet as a source of inspiration as the credibility of the published information needs to be questioned.

The topic of catastrophe modelling has been covered extensively from the viewpoint of the primary property insurer and the property catstrophe excess of loss reinsurer. We have tried to also represent the needs of actuaries working for other insurers and reinsurers in this paper.

We had hoped to produce a public access catastrophe model but have not had enough time to do this. This could be a project for a future working party.

In recent years the term "catastrophe modelling" has tended to be associated with the relatively sophisticated software that has been produced by companies such as AIR, EQE and RMS. In this paper such sophisticated models will be referred to as CAT models to distinguish them from the other, more simplistic models which are the main subject of this paper.

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Reading, web sites and references.

1. Introduction

The 1990's were the United Nation's "Decade of Natural Disaster Reduction". In the insurance community we have witnessed the rapid expansion of the use of sophisticated CAT models that bring together the expertise of seismologists, meteorologists, structural engineers and insurers. There are various research programs (eg RPI, TSUNAMI) sponsored by the insurance community investigating the application of science to disaster reduction and evaluation of potential loss costs. We have also witnessed the two costliest natural catastrophes (in real terms) ever. The attention of the world has been focussed on the potential impact on the climate of man-made emissions of greenhouse gasses. In the US shortages of insurance capacity have led to the creation of a number of state-sponsored pooling arrangements for catastrophe exposures. The US government is currently considering proposals for a federal insurance scheme for the costliest natural disasters. Catstrophe Bonds and other non-traditional ways of transferring catastrophe exposures have become more common. Catastrophe options are traded on several exchanges.

In this paper we concentrate on the perils of earthquake and windstorm. However, as the discussion is quite general in nature similar considerations may apply to other natural and man-made catastrophes.

In many cases CAT models are well suited to quantifying the potential impacts of catastrophic events on a given portfolio of insured risks. However, there are several reasons why the practical actuary needs to be able to develop catastrophe models herself, rather than rely on having access to one or more of the off-the-shelf products. These include:

- licenses for CAT models are not cheap. Although the actuary's company may have some licenses for a particular model, the software and dongles (if any), may well be installed on the property underwriters' machines. This may make it difficult for the actuary to gain access to the models.

- the CAT models require accurate, detailed data in order to produce results that aspire to a similar degree of credibility. In many cases, particularly in the London Market reinsurance environment, the data available may not be sufficiently detailed (or reliable) to justify the use of a detailed model. For example, for a Risk XL reinsurance of a world-wide commercial property account the cedant may only provide a territorial breakdown of premium volumes by continent, so that it is not clear which properties in the risk profile are in a particular territory.

- the CAT models are designed primarily to pertain to mainstream property risks. However, they may not cope well with non-standard property risks. For example, theme parks or power stations.

- the CAT models are designed primarily to pertain to property risks. However, catastrophes can affect other classes. Although the majority of insured losses from an event may well be in respect of the primary property classes, other classes may be significantly affected. Examples include windstorm affecting marine and motor; flood affecting agriculture; an earthquake leading to losses to workers compensation, personal accident, or casualty clash business.

- the CAT models may not cope well with non-standard insurance coverages. In particular, they may not be designed to work with commercial/industrial property business placed on an excess basis. This is important as a large part of major catastrophe losses, in particular from earthquakes, is expected to arise from commercial and industrial property. For example, the analysis of the 1995-6 California Department of Insurance earthquake questionnaire suggests that 80% of the losses from a major event could be from commercial property. Of this about 50% is expected to be recovered from Risk XL reinsurance. The following figures are taken from Tables 2 and 3 of that report and relate to the position at 1994:

San Francisco $'000	Residential	Commercial	Total
Gross PML	3,393	8,336	11,729
Risk XL	X	4,120	4,120
Aggregate XL	X	X	2,088
Net PML	X	X	5,521

- the catastrophe element of the overall coverage may be relatively small (say, less than 20% of expected losses), so it may not be worthwhile performing an overly sophisticated analysis. Given the usual time constraints, time spent on such analysis may be more usefully spent in trying to quantify the residual non-Cat element of expected losses.

- the territory in which the insured is exposed may be one for which there is no available CAT model.

- although a CAT model exists for the exposed territory, the amount of business written in that territory by the (re)insurer may be relatively small, so it is not deemed worth the expense to purchase such a model.

- if we are interested in trying to quantify the economic or industry losses then it is less important to have a detailed breakdown of the exposed properties by location and construction type, etc.. In such cases it may be better to use actual historical loss data which has been "as-iffed" to allow for changes to the exposure profile by the use of inflation indices, changes in building standards, population from census data and so on. Why use a model of reality when there is reality to use? This could be more appropriate in those territories where there haven't been major changes in the exposure base. CAT models are very useful in the US due to the rapid development of properties in perilous regions. The building stock of Northern Europe has not had the same degree of transformation so it may be more appropriate to use a simple as-if approach there.

- the nature of an insurance product may not be readily amenable to modelling using CAT models. For example, the WinCat cat bonds issues by Winterthur which are triggered if there is an event causing damage to more than 6,000 cars. The modelling of these were discussed in ASTIN Bulletin 5/1999.

Catastrophes potentially impact many aspects of managing an insurance entity. An actuary working for such an entity may be involved directly or indirectly in helping to manage several of these impacts. These include:

- estimating the expected loss cost of individual Cat-exposed contracts so that a suitable amount is included within the price of the contract

- estimating the Probable Maximum Loss (PML) of catastrophic events on the portfolio of insured risks, by class and territory. In particular, assessment of the value of the various Lloyds' Realistic Disaster Scenarios if the entity is a Syndicate

- assessing an appropriate capital allocation to be applied to Cat-exposed risks in order to derive Return on Capital when pricing business.

- determining the target amount of Catastrophe reinsurance (traditional or otherwise) to purchase.

- determining the expected loss cost of the Catastrophe reinsurance purchased in order to judge the value-for-money of a proposed reinsurance program

- determining the expected loss cost of the Catastrophe reinsurance purchased in order to be able to notionally allocate the actual cost back to the underwriting teams producing the exposure so that their expected profitability can be more reliably assessed and compared.

- monitoring the aggregate exposure to various Cat events on business written to determine whether underwriting authorities are being breached.

- investment policy - term and liquidity. Note that S&P use a "Catastrophe Liquity ratio" as part of their assessment of an insurer's financial strength.

- allowing for the potential impact of catastrophes when performing a Dynamic Financial Analysis (DFA) study.

We aim in this paper to provide some assistance to an actuary who has been asked by her management to provide quantitative assistance with issues such as those listed above.

Catastrophe models will also be of interest to governments, regulators, rating agencies, bond holders, shareholders, non-insurance companies, and a range of other entities. However, for the purposes of this paper we will concentrate on some of the practical problems faced by a general insurance actuary in her day-to-day job.

2. Types of model.

There are a variety of types of models that could be used. We shall discuss several, from the most simple to models which aim to mimic the methodology of the more sophisticated models. The type of the model used may depend, to some extent, on what statistic is required. For example, we may have models designed primarily to evaluate PMLs or models designed to estimate annual expected loss costs.

The types of models can be represented in a table such as that shown below. Some of the examples will be mentioned in later sections of this paper:

	Point Estimate	Mathematical distribution	Pseudo-Empirical distribution
Total losses	Estimate of the PML of the global insurance community.	Severity distributions fitted to global or continental catastrophe experience.	
Region or peril specific	PML%s as appled in the California Department of Insurance questionnaire.	Poisson-Pareto model fitted to UK windstorm experience in "Storm Rating in the 1990's", GISG 1992.	CAT models used to price Cat Bonds/options.
Company specific	PML for a particular company used in reinsurance purchasing decisions, solvency regulation or credit rating.	Curve fitted to a simulation of the company's actual catastrophe exposed writings.	CAT model that makes allowance for the actual exposure profile of the company.
Risk specific	Cat load in rating manual which makes allowance for various features of the risk. e.g. credit for anti-seismic retrofitting.	Frequency/Severity distributions which are a function of various risk factors of the specific risk.	CAT model that takes into account the precise location of a risk, soil conditions, distance from fault, local attenuation characteristics - eg design standards of nuclear power stations.

At the very simplest level a Cat model may consist of no more than a PML% that is applied to the aggregate exposed to a particular type of event. This would give a point estimate. For example, in order to estimate the impact of a 100-year return period Southern California earthquake we may apply 5% to the total aggregate exposure in that territory.

A higher level of sophistication would be provided by having a probability distribution of the percentage damage to the aggregate exposed to a particular type of event. For example, we may select the distribution to be a Single Parameter Pareto with a certain Alpha such that:

Probability (% Loss > x) = 1% * (5% / x) ^{Alpha}
i.e. so that the100-year event causes 5% damage, as in the previous paragraph.

In this paper we will give some references to such distributions that other authors have fitted to actual data, or have suggested may be appropriate.

As models become more sophisticated they will take account of more factors specific to the risks covered, and will generally require increasing amounts of data.

Much of the exposure to catastrophes is passed to the reinsurance market. In the transition from insurer to reinsurer there is much loss of data. This is continued as the reinsurer retrocedes this exposure. The majority of the exposure to large catastrophes ends up in the accounts of reinsurers who often receive relatively little, poor quality, data.

The following sections discuss catastrophe models at increasing levels of detail.

3a. Point Estimates / Expected losses

When pricing business we require a point estimate of the unconditional expected loss cost to a contract. For some classes of business this will be achieved by applying a rate to the appropriate measure of exposure. For example, we may apply a rate to the sum insured of a household property risk. This rate will typically vary by certain risk characteristics of the insured property such as location and construction type. In many countries the rates to be charged for some perils may be determined by a tariff regulated by the government or insurance regulator. For example, see (http://www.consumerwatchdog.org/public_hts/earth/cea/rates/) for a list of rates charged by the California Earthquake Authority (CEA) for different Zip codes in California. These are now out of date following a recent rate reduction. This site also has lots of other useful, and critical, information about the CEA. Rates for other territories can be found in the CRESTA manual and also in insurance market databases such as those produced by AXCO (http://www.axcoinfo.com/)

In the US and other territories, the rates to be charged for windstorm losses were often determined historically by the use of so-called Excess Wind rating methods. In simplistic terms this involved averaging the amount of wind losses above a certain annual aggregate amount for a period of years and applying the calculated rate to the following period. See "Pricing the Hurricane Peril – Change is overdue" by Chernick, (CAS, Ratemaking 1998) for a description and critique of this approach.

3b. Point Estimates / PMLs

At the simplest level catastrophe PML modelling may consist of nothing more than a percentage being applied to the aggregate sum insured, or some other measure of exposure, in a particular territory in order to estimate the amount of a PML event.

A PML is a point estimate of the expected losses from a "major" event. There is a more detailed discussion of the meaning of PML on the next page. Such an estimate has uses such as:

- a regulator may like to check that the insurer has sufficient capital to meet its PML losses, after allowing for reinsurance, and to monitor the insurer's dependence on the continuing solvency of its reinsurers.
- an insurer may want to ensure that it buys enough vertical catastrophe reinsurance coverage so that the PML does not exceed the limits purchased.
- a rating agency may want to assess the extent that an insurer's claims-paying ability would be affected by a major event.

Although simple, this method is still widely used in assessing PMLs.

For example, the California Department of Insurance requires all property insurers licensed in the state to complete a biennial questionnaire detailing their insured property exposures and the corresponding PMLs. The questionnaire specifies PML% to be applied to the aggregate exposure by zone and construction type, although insurers are allowed to use CAT models instead. The table in Appendix A shows the PML% to be applied in the 1995-6 questionnaire. These PML% were derived from analysis of previous experience.

Although this may appear to be a simple calculation, namely:

PML = a measure of exposure * a measure of loss as % of exposure we should consider, inter alia:

(i) what is meant by the term PML?
(ii) what is a suitable measure of exposure?
(iii) how do we measure the exposure?
(iv) how do we determine an appropriate PML%?
(v) how does the PML% depend on the nature of the underlying risks?

Some examples may make it clearer that these issues are not as simple as they may firs appear.

(i) what is meant by the term PML?

This term was originally used by property underwriters to mean the largest loss that a single property could be expected to suffer due to a fire, explosion, or other non-cat event. It has also been adopted to apply to the aggregation of losses arising from a single event. The term does not have any universally accepted quantitative definition.

The term "probable maximum" seems to indicate that there is less than a 50% chance of a loss larger than this occurring. We know that the intent of the term PML is to indicate a rare event. If the PML loss was the size of event that we may expect to occur no more frequently than once in 150 years, say, then there would be less than a 50% chance that we'd observe one in a 75 year period. Roughly speaking then, a PML event is of such a size that there's roughly a 50/50 chance that one of this size, or more, would occur during an average lifetime. This definition is just intended to be a rule of thumb.

Note that we are concerned here with probable maximum (insured) LOSS. We are not concerned (in this paper) about big earthquakes, strong hurricanes, or other natural catastrophes that affect sparsely populated (or sparsely insured) areas.

(ii) what is a suitable measure of exposure?

The simple, intuitive, answer may be "the sum insured".
This may well be true for primary relatively low sum-insured property business.
However, the same is not necessarily true for other types of insurance.
Some examples:

a) facultative excess of loss business

An excess of loss (re)insurer may write a \$1M line on the following risks:

100% line on \$1M xs \$1M on a \$2M warehouse
1% line on \$100M xs \$100M on a \$1Bn industrial complex

Should these count equally in the exposure base, as both have the same "sum insured" as far as the insurer is concerned?

b) risk excess of loss business

A treaty may cover several territories (e.g. world-wide excl. USA, or nation-wide with in the USA) and have limited reinstatements. Let us say that we have the following information:

Layer $10M xs $10M , 2 reinstatements

State	Number Risks exposing layer
California	90
Nevada	70
Oregon	60
Washington	90

We deduce that the maximum amount recoverable from the treaty is $30M.
How should we allocate this?
Should we count $30M in the aggregate exposure for each state?
Should we allocate the $30M between the states in some way?
Should we allocate less than $30M between the states?
If so, how?

C) large-value industrial property

For large-value properties the total value of the property may not be a reasonable estimate of the exposure. In assessing a suitable premium for the non-Catastrophe exposure of such properties underwriters typically use the Expected Maximum Loss (EML), Maximum Foreseeable Loss (MFL) or PML. These terms (which may or may not be synonymous depending on which underwriter you talk to) and the values attached, are usually intended to represent the potential losses from a very large fire/explosion-type loss.

For example, an insured industrial property may extend over several hectares, possibly consisting of several disjoint buildings. For such an insured property it would be quite unlikely that the whole of the sum insured would be destroyed in a non-catastrophe. However, a catastrophic event could well affect all parts of such an insured property to a similar extent. This may mean that a severe catastrophe could produce a loss in excess of the "fire" EML

Consider the effect on a risk excess of loss underwriter who has been provided with a "fire" EML profile in the submission for a Risk XL with catastrophe exposure.

D) Marine excess of loss

The marine market has historically relied heavily on statistics such as "Max. line" to determine its exposure to catastrophic events. For example, underwriters A and B may have written lines of various sizes on a variety of underlying risks, which are shown in a risk profile such as:

Line Size band $'K		Number of risks in the band	
Low	Top	U/Wer A	U/Wer B
0	100	90	5
100	250	80	10
250	500	60	20
500	1,000	40	40
1,000	2,000	20	60
2,000	5,000	10	80
5,000	10,000	5	90

In both cases each underwriter may say his Max. line is $10M, and this is his PML to whatever event you care to suggest. This may seem irrational.

It may seem more sensible to estimate the average of line sizes within each line-size band, multiply by the number of risks in the band, sum across all band sizes, then allocate the total aggregate exposure thus calculated between the Cat perils that we are considering, then multiply the aggregate exposure to each by a suitable PML%.

However, it may be the case that the small lines are shares on working layers which have event limits so have relatively limited catastrophe exposure, whereas the large lines are on more remote layers that are mainly exposed on an occurrence rather than a *per insured (e&el) basis* (as many Marine risk XLs are written on a per occurrence AND/OR per insured basis).

It may therefore not be quite so irrational to use the maximum line as a measure of the PML, after all, in some cases. However, it does seem anacronistic for the marine market to continue to use such simplistic measures given the advances in catastrophe modelling made in the non-marine insurance market.

(iii) how do we measure the exposure?

Let us say that we write US primary homeowners business and want to estimate our exposure to a major earthquake in northern California. Let us assume that we know the precise location of each of our insured properties in California and adjoining states. Which properties should we count in our exposure base?

Even if there was a large quake epicentred on San Francisco, it would probably not cause much, if any, damage 550 Km away in Los Angeles. So, should the properties in distant states and counties be included in the exposure base? If not, then where do we draw the line between those properties included or excluded from the exposure base?

This issue has been partially resolved in the various zonation protocols such as CRESTA zonation, or the California Department of Insurance Earthquake zones.

<u>(iv) how do we determine an appropriate PML%?</u>

This issue is interlinked to the measure of "as-if" exposure that has been chosen.

In some situations there may be industry analyses which we could use for guidance, such as the Californian Earthquake PML questionnaire reports.

Another way to estimate a potential value is to look at historical experience after making allowances for quantifiable exposure changes such as population growth, price inflation and the percentage of risks which are insured, and making allowance for the potential for a PML event to be larger than any in the experience period. For example, in reinsurance submissions of UK property catastrophe XLs the "as-if" value of the H90A windstorm loss to the reinsured is often quoted as a guide to the possible size of the PML loss.

This may be done in detail for each cat peril/zone or may be done in detail for one cat zone, with the PML%s for other Cat peril/zones selected judgementally such as to be consistent with the region analysed in detail.

<u>(v) how does the PML% depend on the nature of the underlying risks?</u>

In theory the PML% applied should vary by a range of risk factors such as the construction type, hazardousness of occupation, fire protection standard, size of sum insured, etc. In particular, especially for a portfolio of Risk XL or excess facultative risks the attachment point should make a large difference. This indicates that a PML calculated by this simple method could be improved if the risks in the underlying exposures could be grouped by various risk factors and different PML% applied to the different groupings. One difficulty with this approach is that it is difficult enough to obtain reliable PML%s in the first place, so it will be even more problematical to obtain different PML%s for the different combinations of risk factors. However, even though the absolute size of the PML% may be in question, having different PML% that incorporate the expected relativities between risk factors will generally be better than using a single factor. At least by having different factors the impacts of following different underwriting strategies can be estimated.

4. Simple Catastrophe distribution function models

Another way of thinking of PML events is to consider them as the high percentiles (e.g. The 99.5th percentile) of the unconditional severity distribution of loss amounts. In this section we consider the estimation of PML and other loss sizes by the use of severity distributions. It can be dangerous to rely on the values derived from the far tails of statistical distributions. This also applies to the output of the most sophisticated CAT models. However, in trying to quantify catastrophe losses we are, by definition, dealing with the tail of the distribution.

Severity distributions may be required in at least two different formats. We may want either:

(i) the severity distribution of the aggregate amount of losses

(ii) the severity distribution of loss amounts for individual losses as a percentage of the insured value within a given event, or for all potential events.

The topic of fitting distributions to Catastrophe experience has been widely covered elsewhere, and we do not intend to add anything to the subject in this paper. The reader is referred to the original papers mentioned below in order to obtain further details of the considerations the authors gave to their selections.

Aggregate severity distributions over time

When fitting, or choosing, an aggregate severity distribution it is necessary to bear in mind whether per-occurence distribution (i.e. the probability distribution of the size of an event given that an event has occurred), or a distribution for all the events that could occur in the period of interest is required. You also need to consider whether you want a conditional or unconditional distribution. We will consider multiple events in the next section. The remainder of this section lists some papers in which claim severity distributions have been fitted to catastrophe experience.

Cummins, Lewis & Phillips :Pricing excess of loss reinsurance contracts against catastrophic loss

This paper sets out to find a pricing basis for the so-called MegaCat reinsurance contracts that were proposed by the Clinton administration to provide Federal reinsurance coverage against very costly catastrophes that are not currently covered by the private sector. In particular the paper considers the expected loss cost to a nation-wide catastrophe excess of loss contract of \$25Bn xs \$25Bn. The motivation behind such a Federal scheme is to provide inter-generational smoothing of the impact of catastrophic losses in order to mitigate against severe dislocation of the insurance market that might occur if a MegaCat were to occur.

To do this the Property Claims Services' (PCS) database of historical catastrophe losses was adjusted to allow for price and exposure level using a construction cost index and census population data. Also, Risk Management Services (RMS), a catastrophe model provider, was commissioned to provide estimates of the nation-wide distribution of catastrophes. A variety of statistical distributions were then fitted to the resulting observations. The fitted distributions' parameters are shown in table 3 of that paper

For example, the Pareto distributions fitted had Alphas of approximately 0.3 to 0.5 depending on the territory involved. However, the authors concluded that based on goodness-of-fit criteria the Pareto was too thick-tailed.

SCOR Prize 1992 : various papers, various distributions
In "Ratemaking for natural events coverages in the USA" the authors took PCS data and trended for inflation, population growth and the insured share of economic losses. This trending was based on the approach postulated by Don Friedman. The authors reject the single parameter Pareto with fitted Alpha of 0.465 as being too heavy-tailed and conclude that the best fitting distributions were Truncated LogNormal, Weibull or LogGamma. This was the distribution fitted to 37 hurricanes in the period 1954-1986 which caused as-if insured damage of at least $30M.

In "Measuring the probability of disastrous losses" the authors fit a Pareto distribution to American Red Cross expenditure data which were trended by consumer price inflation. The authors introduce a novel way to try to overcome the problem of bracket creep inflation which may be useful outside the realm of catastrophe modelling. Their enhanced model produces an estimate of the Pareto Alpha of 0.96. Clearly, there is a basis risk here as Red Cross expenditure data is not the same as insured losses.

Hurricane Andrew and Northridge quakes were not included in the above two papers' datasets as neither had occurred at the time they were written. It would be interesting to see what difference including these would make in the analyses.

Cristofides et al : Storm rating in the 90's

This paper resulted in the selection of a single parameter Pareto distribution with alpha 1.26 for UK windstorm losses.

CAS Forum 1999 Securitisation of Risk: "Uncertainty in Hurricane Risk Modeling and implications for securitization.", D Miller.

This paper tried to estimate the amount of model and parameter uncertainty in a certain, CAT model. The author fitted a Beta distribution to the losses simulated by the CAT model being used.

DynaMo Public Access DFA model
This is a DFA model produced by the US firm of consulting actuaries Miller, Rapp, Herbers & Terry Inc. It is freely downloadable from www.mrht.com and was described in the Summer 1998 CAS Forum book. It contains a matrix of LogNormal severity distribution parameters fitted to trended PCS data for each state in the US.

Severity distributions of losses as % of insured value

We will need the second type of severity distribution, (ii) above, when pricing Risk XL business, or when trying to estimate the effect of applying a deductible to primary business.

When rating risk XL business it is common practice to apply the sum of a non-cat and cat rate to the sums insured to obtain the required ground-up risk premium rate and then to calculate the proportion of this ground-up risk premium required for the layer being by using a first loss curve. This implicitly assumes that the conditional severity distribution of the non-cat losses is the same as the conditional severity distribution of the cat losses. This is unlikely to be the case in general. In fact in Ludwig's seminal paper "An exposure rating approach to pricing property excess-of-loss reinsurance" a first loss curve fitted to Hurricane Hugo losses is provided which does differ from the non-cat first loss curves shown. In general we may expect the shape of the distribution to vary according to the peril as hurricanes tend to produce more small losses but fewer total losses compared to the losses produced by a major earthquake.

What we ideally need is to obtain the severity distribution which is the weighted average of the severity distributions of all the potential events. This is similar to the requirement for an annual expected loss cost to include the expected losses from all potential events. The main difference is that the expected loss cost is unconditional whereas the severity distribution required is conditional. That is, the probablity of no loss is included within the premium rate, but once a loss occurs the severity distribution will determine the expected distribution of losses to the excess of loss layers.

To derive a first loss curve applicable to a given peril/zone from the cat premium rate we could consider the following approach:

(i) strip out the estimated loadings for expense, profit and so on from the cat rate to obtain a pure risk premium.

(ii) estimate the probability of there being a catastrophic loss of a size that would lead to claims from the cat coverage. For example, if the cat rates are based on a certain policy deductible then the selected probability should allow for this.

(iii) divide the rate in (i) by the annual probability of loss from (ii) to obtain the expected average size of loss given that there is a loss.

(iv) judgmentally select a severity distribution family (eg Lognormal) and a standard deviation around the mean derived in (iii).

(v) integrate the expression : $^{L}\int x.f(x)dx + L(1-F(L))$, to obtain the first loss curve.

(vi) try varying the various judgmental parmeters above to test the sensitivity of the first loss curve. For example, if there are several cat zones involved we may like to consider whether we should treat them separately or in the aggregate - does this make any difference to the prices then implied for the risk XL layers?

It may be possible to refine the assumptions required in this process.

For example, let us assume that we could obtain a conditional severity distribution for a quake of a given intensity (how we might do this is considered in a later section). By using the Gutenberg-Richter relationship, which describes the return period as a function of earthquake magnitude, of the relative number of events of different intensities in a region we could then obtain the weighted average severity distribution for events above a certain intensity. See "US Earthquake frequency estimation - ratemaking for unusual events" by Stuart Mathewson, CAS Forum Winter 1999 for a discussion of the Gutenberg-Richter relationship. We could verify that the distribution obtained was reasonable by calculating the implied conditional loss cost and multiplying my the probability of there being an event of at least the minimum intensity in the period and comparing the result to the expected loss costs used in (i) of the method above.

5. Frequency distributions

For many applications it will not be enough to consider the severity distribution of a single potential event, as potentially the subject account may be exposed to a number of catastrophes in a given period. For example, in a single hurricane season there may be major hurricanes which could make landfall in, say, Florida or Mississippi. If we were a reinsurer who had exposures in both states we would therefore also want to be able to consider the possibility of neither, one, or both states being affected by different (or the same) hurricanes.

As in the last section we do not propose to provide an answer as to the most appropriate type of distribution to use, but merely to present and reference other authors' research into the subject.

The most commonly used frequency distribution for low frequency events such as catastrophes is the Poisson. This has the important property of being memoryless. That is, the probability that an event occurs in a given period is independent of all previous events. Many authors who have investigated the frequency distribution of catastrophes conclude that the Poisson is a suitable distribution to use. Often this is done by testing the significance of the ratio of the observed variance to the mean.

Due to the relatively small amount of data on catastrophic frequencies that is available we are generally constrained to use much if not all of the available experience. Thus the estimates of frequencies obtained are often the long-term (or at least medium-term) estimated frequencies. This may be suitable if the underlying frequency could be reasonably assumed to be stationary.

However, there are several reasons why this may not be appropriate. These include:

(i) Cycles in climate (e.g. ENSO). See Bill Gray's Hurricane forecast (http://typhoon.atmos.colostate.edu/forecasts/1999/fcst99/) to see that the frequency of hurricanes is not constant over time. So, although the frequency in any particular year may be indistinguishable from Poisson, over time the distribution in Mixed Poisson - in particular, the Negative Binomial may be a better model over time. Some authors suggest that the past few decades have had an abnormally low level of hurricane activity.

(ii) trends in climate ?
What about global warming ?

(iii) seismic clustering/ aftershocks

Once an earthquake has occurred on a fault the built-up strain is released, but there is then extra strain at an adjacent fault (multi-body slip model ...) . This may make it MORE likely that a quake will occur in the near future in such a nearby fault

(iv) seismic gaps

Once an earthquake has occurred and released the built-up stress it takes a long time for tectonic slip to build up sufficient strain to cause a major quake. Therefore once a quake has occurred it is less likely the another will occur in the near future.

(v) correlations between events

The global climate is intimately interlinked. There are trends (global warming ?), cycles (e.g. ENSO, NAO, QBO) and jumps (Volcanic eruptions, Solar-terrestrial events) that affect large areas of the globe at the same time, though not always in the same way.

(v) location impacts of climate cycles

Trends, cycles and jumps in the climate can also impact the location of landfalling hurricanes. So, a given year may be expeected to have more or less than average hurricane activity overall – this doesn't necessarily mean that the expected frequency of events at any particular location changes in proportion to the overall change.

These argue against Poisson models. However, it is not clear whether this implies positive correlation and hence increased variance (e.g. volcanic eruptions have a global cooling effect which may reduce tropical cyclone frequency and severity everywhere), or negative correlation and hence reduced variance.

It may well be the case that in any particular year the frequency of catastrophe follows a Poisson distribution, but over time the Poisson frequency is likely to vary.

It should be remembered that CAT models do not (currently) make any allowance for cycles in climatic behaviour.

6. Aggregate frequency/severity distributions

Bearing in mind the above comments on the considerations involved in fitting or selecting the severity and frequency distributions we are now able to fit a distribution to the total expected losses.

PML Distributions

In section 3 we gave a practical definition of a PML event as an event of such size that there's roughly a 50/50 chance that one or more of this size would occur during an average lifetime.

From the frequency / severity framework we have constructed we can not only assess what this amount might be but also examine the return periods of other large, rare events to create a distribution of PMLs by return period.

We can do this by examining the probability that our claims process generates at least one loss of the particular magnitude at any time during the period in question. The example below shows how we can do this if our claims are modelled by a Compound Poisson process.

Example

Let us assume our losses are generated in accordance with a Compound Poisson model with a Poisson parameter of λ.

For this model the probability of generating a loss during the period is $1-\exp(-\lambda)$.

From our conditional severity distribution of loss size given that a loss occurs, we can determine $p(x)$, the probability of that a loss exceeds x. Examination of the Laplace Transform of the distribution of all claims above x reveals that they are also generated by a Compound Poisson process but with parameter $\lambda * p(x)$.

The unconditional probability of at least one loss in excess of x during our period is then $1-\exp(-\lambda * p(x))$ and the reciprocal of this probability is the return period for a loss of size x.

Note that the commonly used approximations $(1-\exp(-\lambda))*p(x)$ or $\lambda * p(x)$ do not allow for the second or subsequent losses being larger than the first loss and so understate the true probability. The first of these is increasingly inaccurate as $p(x)$ and λ increase but is still accurate to 5% for $p(x)$ of 50% when λ is below 0.21.

According to our definition, a PML event is the loss with, say, a 150 year return period. However as our example demonstrates we can derive a range of losses and return periods from our frequency / severity model and create a PML distribution.

This approach can be useful if we wish to get away from the single number PML and obtain a range for the size of our PML event. As the next section outlines it also allows us to accommodate exposures in multiple territories or to multiple perils within one territory which is difficult to do sensibly if we are working from a simple list of PMLs.

Multi-territory/peril PML Distributions

Let us assume we have a series of exposures i=1,2...n, each of which generates losses S_i i=1 to n, each modelled by Compound Poisson process with parameter λ_i and severity distribution functions $F_i(x)$ i=1 to n.

It is a well known result that the total loss

$$S = S_1 + S_2 + \ldots + S_n$$

is a Compound Poisson random variable with Poisson parameter

$$\lambda = \lambda_1 + \lambda_2 + \ldots\ldots + \lambda_n$$

and claim severity distribution

$$F_X(x) = \Sigma_j \lambda_j/\lambda\, F_j(x).$$

Therefore our new severity distribution is the weighted average of the severity distributions from each territory where the weights are the proportions by which the frequencies in each territory contribute to the overall frequency. From this we can determine the p(x) as defined above for each loss size and again calculate the probability of a loss of that size in the period as $1-\exp(-\lambda * p(x))$ or else go further and determine the full worldwide PML distribution.

George Walker in the section "PML Return Periods" of his paper "Current Developments in Catastrophe Modelling" (see part 1) discusses the need to be able to generate worldwide PML return periods in order to get full value from catastrophe models. The above demonstrates how this can be achieved when we are working with a simple frequency / severity model.

7. Simulated distributions

A problem with some of the above methods is that they do not take account of the nature of the underlying exposures. This is especially true for reinsurers.

Let us consider the case of two portfolios of catastrophe reinsurances, A and B. A consists of mainly relatively low down, high rate on line, layers, whereas B is mainly relatively remote, low rate on line layers. A and B could be different companies or could be two different strategies that a given company may be considering adopting.

Intuitively we know the distribution of losses that A will experience is expected to be less volatile than those of B.
How may we attempt to quantify the difference?

Mathematically modelling this problem analytically (ie using functions) will be intractible because the line sizes on different risks may be different. This could be exacerbated by, say, B writing shares on the third and fifth layers in a program, but not on the fourth. Also, there could be differences between the coverages offered by different layers. For example, one program may cover all perils up to a certain level, but provide flood-only coverage in the top layer.

One way to overcome such problems is to simulate the potential experience of the actual contracts written using the actual premiums on these risks as a guide to the expected losses. These contracts may well have been priced using CAT models. The steps in such a process are roughly described below. Note however, that this process would need to be amended to cope with contracts with high rates on line which have a material probability of having more than one loss in a year:

(i) assume that the business has been priced rationally, and that risk-specific features have been taken account of by the underwriter when setting the price, or deciding to accept a following line at a given price.

(ii) estimate the share of the premium on each contract which pertains to each of the Cat Peril/zones to be used in the analysis. For example, one may want to distinguish between exposures to earthquake and windstorm losses in a given territory.

(ii) estimate the (long-run) expected loss ratio for each Cat peril/zone for each contract written. This should take account of the actual commission, reinstatement provisions, and other terms of the contracts written. There is no reason to necessarily assume that the loss ratio is the same for all contracts, even those within a given program may have different loss ratios selected. Similarly, we needn't assume that the contracts have been written to produce an expected profit at all on some contracts. The underwriter will generally be best placed to make this assessment, or should at least be consulted.

(iii) estimate the average size of loss to each contract given that there is a loss to the layer. This could be done by assuming all losses are total, though it is better to assume that the losses have a certain distribution, such as a Pareto(0.75). Typically the conditional average size of loss to a layer is about 40-50% of the limit.

(iv) multiply the premium allocated to the Cat peril/zone by the expected loss ratio by Cat peril/zone to obtain the (annualised) unconditional expected loss costs for each Cat peril/zone. By summing over all contracts the annual expected loss cost for each peril for those contracts in the sample is obtained.

(v) divide the expected loss cost to the layer by the conditional average loss amount to obtain the expected frequency of losses to the layer, F_{cz}(contract), for each Cat peril/zone

(vi) group together contracts which are part of the same program for a given insured.

(vii) group together those contracts which are exposed events within certain cat peril/ zones. In some cases this may not be straight forward, in particular, if a program covers risks written in large geographical regions (eg Europe).

(viii) For each cat peril/zone simulate the return period of the event which is deemed to occur in the year. The reciprocal of this is the frequency, F_{CZ}, of the event that occurs in the year. This is given by a random sample from the uniform distribution on (0,1). Correlations between the experience of different cat peril/zones can be allowed for at this stage. For example, we could make allowance for El Nino Southern Oscillation (ENSO) effects.

(ix) if F_{CZ}(contract) $< F_{CZ}$ then there is a simulated claim to the layer. The amount of the claim is simulated based on the severity distribution which was used to estimate the conditional average size of loss in (iii) above.

(x) for contracts in a program we then need to ensure that if there is a claim to a high layer, then all the lower layers written by the reinsurer are total losses.

The losses in each Cat peril/zone can then be summed, and the process repeated thousands of time. This is easy to do using simulation packages such as @RISK or Crystal Ball, or can be done by macroising a spreadsheet.

The outputs of the model could include per-Cat peril/zone loss severity distributions, the distribution of losses to the whole portfolio, etc..

In practice, sufficient numbers of simulations should be run such that losses are expected to be generated to those contracts with the lowest adjusted rates on line.

Once this process has been completed it will then be a simple matter to decide whether the aggregate distribution can be adequately modelled using an analytical expression such as a Gamma or LogNormal. Sometimes the resulting distribution may not be modelled analytically. For example, there may be discontinuities produced by unusually large contracts, or where low-level programs are exhausted.

In practice there are several adjustments which may need to be made, or refinements that are desirable. For example, we may want to allow for more than one event to be simulated per Cat peril/zone in the period.

The process described above can be applied to situations other than catastrophe modelling. For example, it may be used for some types of DFA analysis.

This approach is demonstrated in the example below:

Co	Cover	Ded.	Peril Zone	Real ROL	Peril as % ROL	Adj. ROL	Avg to layer	Avg. Freq. layer	Sim peril Freq	Sim Clm	Clm to layer
Note	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
A	1,000	1,000	CA	10.0%	20%	2.00%	40%	5.00%	0.03	543	1,000
A	3,000	2,000	CA	5.0%	25%	1.25%	40%	3.12%	0.03	1,209	1,209
A	5,000	5,000	CA	3.0%	30%	0.90%	40%	2.25%	0.03	4,090	0
B	500	500	CA	15.0%	15%	2.25%	40%	5.63%	0.03	121	500
B	4,000	1,000	CA	7.0%	25%	1.75%	40%	4.38%	0.03	1,209	1.209
C	10,000	10,000	FL	2.0%	20%	0.40%	40%	1.00%	0.76	7,631	0

Notes

(5) : this is the % of the office premium which relates to the expected loss costs from the peril in the zone in col 3.

(6) : (5) * (4) = expected loss cost from peril (3)

(7) : average size of claims to layer given that there's a claim.

(8) : (6) / (7)

(9) : sampled from Uniform(0,1)

(10): sampled from severity distribution used eg Pareto((2),0.75)

(11): if there's a loss to the next layer in program then (1) else (10).

8. Explicit event modelling

The simple distribution-based methods described above do not explicitly allow for all the features of the exposure. For example, it would be difficult to determine how the severity or frequency distribution of hurricanes should vary between insurers who wrote different cross-sections of, say, Louisiana homeowners; one insurer may not write much business, as a matter of underwriting principle, within 10 Km of the coast, whereas the other may have a higher concentration of such business.

There are many factors which affect the distribution of insurance losses from all potential events, including:

Construction type - Wood-frame, Brick, Steel, Concrete, etc.
Type of property - residential, apartment block, factory, oil refinery, etc.
Fire protection standard - spinklered or not, distance to fire station, etc.
Local topography - in lea of hill (wind), in a depression (flood), on a steep hillside (quake), height above sea level (flood), etc.
Local geology - built on bedrock, landfill, sandy subsoil, etc.
Distance from coast
Mitigation measures used - anti-seismic features, storm shutters, flood defences, etc.
Extent of insurance coverage - exclusions, deductibles, building/contents/business interruption,etc.

and so on.

Although we could not expect to be able to produce a catastrophe model as sophisticated as many of those on the market, it is possible to learn from these models and in doing so perhaps find ways to improve the more simplistic models.

CAT models typically consist of the following modules:

Event generation : where events with certain features (such as quake intensities and locations, windstorm windfields and paths over land) are simulated
Mitigation : where allowance is made for any mitigation features such as flood defences
Damage : where the simulated intensity of the event is converted into an amount of damage to the insure property.
Insurance : where the terms of the insurance contract are applied in order to calculate the loss to the insurance contract.

For a more detailed description of these see for example,

- Catastrophe Modelling Working Party 1997 GISG paper,

- http://www.wsspc.org/summit/eqiperspectives5.html,
- "Catastrophe Ratemaking Revisited (Use of computer models to estimate loss costs) Walters & Morin CAS 1996.
- General Re's cat modelling site at www.clough.com/CLOUGH.nsf/Doc/catmodelgroup
- the CAS website (various papers, see for example the session 12 papers from the 1998 Catastrophe Seminar www.casact.org/coneduc/specsem/98catast/houts.htm)

In order to construct a simple model we could consider each module in turn.

As the considerations differ between different types of catastrophe we will consider earthquakes an hurricanes separately.

In what follows we are not intending to prescribe the way that a model should be constructed, or recommending any particular parameterisation or calibration, but merely illustrating the principles involved. This, it is hoped, is illuminating as it shows deficiencies in the data available to calibrate models.

It is useful to understand what the modellers do to build their models. In particular, the CAS is considering that using CAT models, understanding how they work, and understanding the level of uncertainty in their output, may be an issue for mandatory professional standards.

8a. Earthquake model

In this section we will consider how to construct an earthquake model.

By building our own model we can illustrate some of the areas of uncertainty. We can also test the sensitivity of the results to the model parameters.

The steps that we will use are:

(i) **Rupture details**: we will estimate the rupture length and the depth of the hypocentre.

(ii) **Attenuation**: for a quake of a given epicentral intensity we will estimate the intensity in the surrounding areas. That is, we will estimate the isoseismals surrounding the epicentre.

(iii) **Damage %**: we then apply a damage function which estimates the mean amount of damage for a given intensity of shaking at a location.

(iv) **Estimate of variability within each intensity band**: we estimate the distribution of damage % within each intensity band.

(v) **Return Periods**
We will not discuss these at any length as they were covered in the excellent paper "US Earthquake frequency estimation - ratemaking for unusual events" by Stuart Mathewson, CAS Forum Winter 1999.
However, the interested reader may like to know that at the following website you are able to select a location by latitude and longitude and specify a radius of interest to obtain a list of earthquakes that are recorded as having epicentres in the defined circle.
wwwneic.cr.usgs.gov/neic/epic/epic_circ.html

(vi) Exposure base.
We then need to apply the above model to a given exposure base. For the purposes of generating a generic first loss curve we will need to make a judgemental estimate of the distribution of properties within the area affected by the modelled event.

The above model is intended to apply to one particular type of property. The same model could be calibrated differently for different property types.

We will use the following terminology in the rest of the paper:

MM = Modified Mercalli intensity scale. This measures the severity of a quake by using observed levels and types of damage. See appendix B.

RM = Richter magnitude scale. This measures the severity of a quake using the measurements of seismographs. It is intended to represent the amount of energy release in a quake.

PGA = Peak Ground Acceleration. A measure of the maximum amount of shaking as recorded on a seismograph.

We discuss below each of the steps mentioned above in more detail.

(i) rupture details:

The magnitude of an event is correlated to the length of the fault that ruptures in an event. The length of the rupture can vary depending on the type of fault. For example, Slip-thrust faults (where the tectonic plates are sliding past each other) are different from subduction faults (where the tectonic plates are sliding towards each other). Also, the length of the rupture will affect the shape of the area affected at various intensities (ie the isoseismals). Short ruptures will, all else equal, produce approximately circular areas affected by a given intensity. Longer ruptures will tend to produce elliptical areas instead.

The depth of the rupture will also affect the magnitude of the quake, and will also, more importantly, affect the attenuation characteristics. Shallow-focus quakes will generally attenuate more quickly than deep-focus quakes. The average focal depth will depend on the type of fault and the local geology. For a slip-strike fault a typical depth might be 10Km, though some quakes have depths of 100's of kilometres.

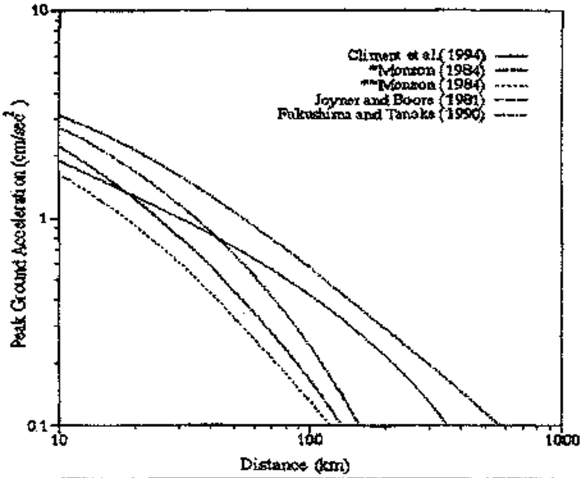
The focal depth of quakes is estimated by calculating the time difference between the arrival of different types of seismic at seismic stations.

The length of a rupture and the hypocentral depth will vary even for events that could occur in a given region. In this following sections we model the consequences of a quake of a given rupture length and depth. To build a more robust model we would need to make allowance for the variability in these factors.

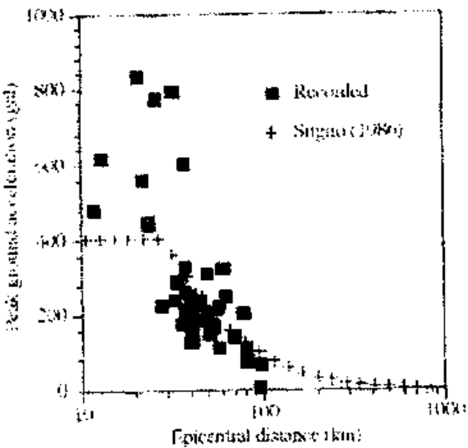
(ii) Attenuation:

We need to estimate the way that the intensity of an event typically decreases as distance from the epicentre increases. This is called attenuation. The term attenuation is used by seismologists to describe the way that certain statistics such as Peak Ground Acceleration (PGA) as measured on seismographs vary with distance from the epicentre. Such attenuation functions are used to extrapolate from seismograph readings to calculate the Richter magnitude of an event, as this is stated in terms if a hypothetical seismograph 100 Km from the epicentre.

The graph below shows a few different attenuation functions suggested by different authors. See the paper at the website named below the graph to obtain more details of these:



Source:www.eas.slu.edu/people/students/JPLigorria/msc/msc.html



Source: http:\\rccg03.usc.edu/reports/report3/japan/figure3d.html
This shows the actual attenuation observed in the 1995 Kobe earthquake.

The equation of Climent et al shown on the previous graph is given by:

$$\mathrm{Ln}(PGA) = -1.687 + 0.553M - 0.537\mathrm{Ln}(R) - .00302R + 0.327S + \mathrm{Normal}(0,0.6)$$

Where,

PGA in units of cms^{-2}
M = Richter moment of magnitude
R = hypocentral distance in Km
S = 0 if Rock, 1 if soil at site of measurement.

This is intended to apply to Guatemala

Www2.ced.berkley.edu:8002/newark/conventional.html gives the following formula:

$$\mathrm{Ln}(PGA) = 0.828 - 0.144(M-6.4) - 0.1020(8.5-M)^2 + (-0.838 + 0.17(M-6.4)\mathrm{Ln}(R)$$

Where,

PGA in % of gravity
R = epicentral distance in Km

Erp-web.er.usgs.gov/reports/abstract/1998/PN/G1513.htm gives the following formula:

$$Ln(PGA) = 6.36 + 1.76M - 2.73Ln(R + 1.58exp(0.608M)) + 0.00916H$$

Where,

PGA is measured in gals (this is g/1000)
R is the epicentral distance in Km
H is the focal depth

Erp-web.er.usgs.gov/reports/fintech/1998/G2488.htm gives the following formula:

$$Ln(PGA) = 0.518 + 0.387(M-6) - Ln(R) -0.00256R + 0.335S$$

Where,

PGA is measured in g
R is the hypocentral distance in Km
M is the magnitude
S is a soil type indicator (1 or 0).

The above attenuation relationship is intended to apply to Hawaii.

www-socal.wr.usgs.gov/wald/1906/1906.html

suggests the following formula:

$$Ln(PGA) = 2.17 + 0.49(M-6) - Ln(R) - 0.0026R + 0.17S$$

As being suitable for San Fransisco.

For many more attenuation relationships see also geohazards.cr.usgs.gov/engnseis/eshmpage/shalactreg.html

For even more try erp-web.er.usgs.gov then search the site.

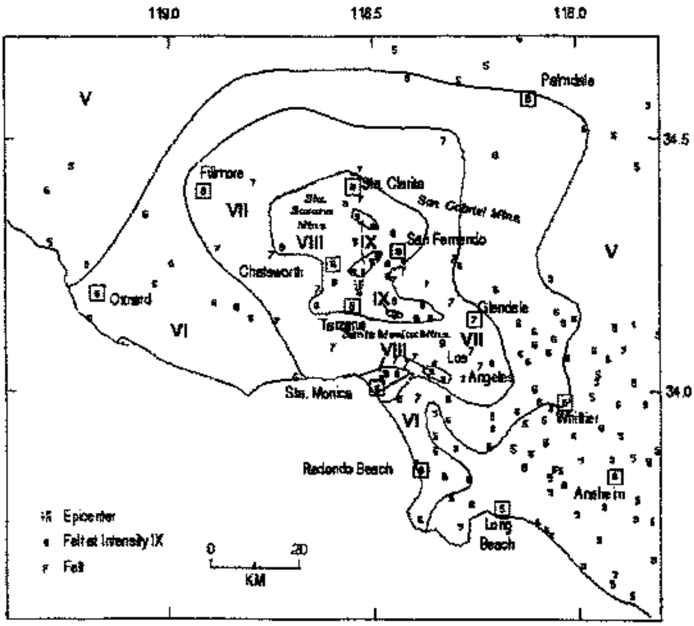
Formulae of this form are roughly equivalent to:

$$PGA = Constant(function of magnituge) * R^{-exponent}$$

Note that for the specific formulae above the multiplicand of Ln(R) gives the exponent in this general formula. The exponents in the above are: 0.537, 0.838 - 0.17(M-6.4), 2.73 and 1.00. This is quite a wide range. This shows that attenuation functions vary by area, so we should be wary about using a generic function.

In the case of cat models we need to produce an attenuation function which is quantified in terms of the intensity of the event. The amount of shake-damage that is caused at a given location is correlated on the strength of shaking, which is measured by the PGA. Some authors suggest other measures are better correlated with damage. For example, the producers of GeoRAWS, a catastrophe model [www.georisk.com/georaws/docum/vuln.htm], suggest that spectral velocities and spectral accelerations are a better measure. Also, the new HAZUS methodology employed by the US's FEMA/NIBS uses spectral accelerations rather than PGA.

The following map shows the isoseismals of the Northridge, CA, 1994 event. That is, it shows the areas affected by different levels of MM intensity. This had a rupture length of 14Km.



Source: www-socal.wr.usgs.gov/north/mmi.html

This shows how the MM intensity attenuates with distance from the epicentre.

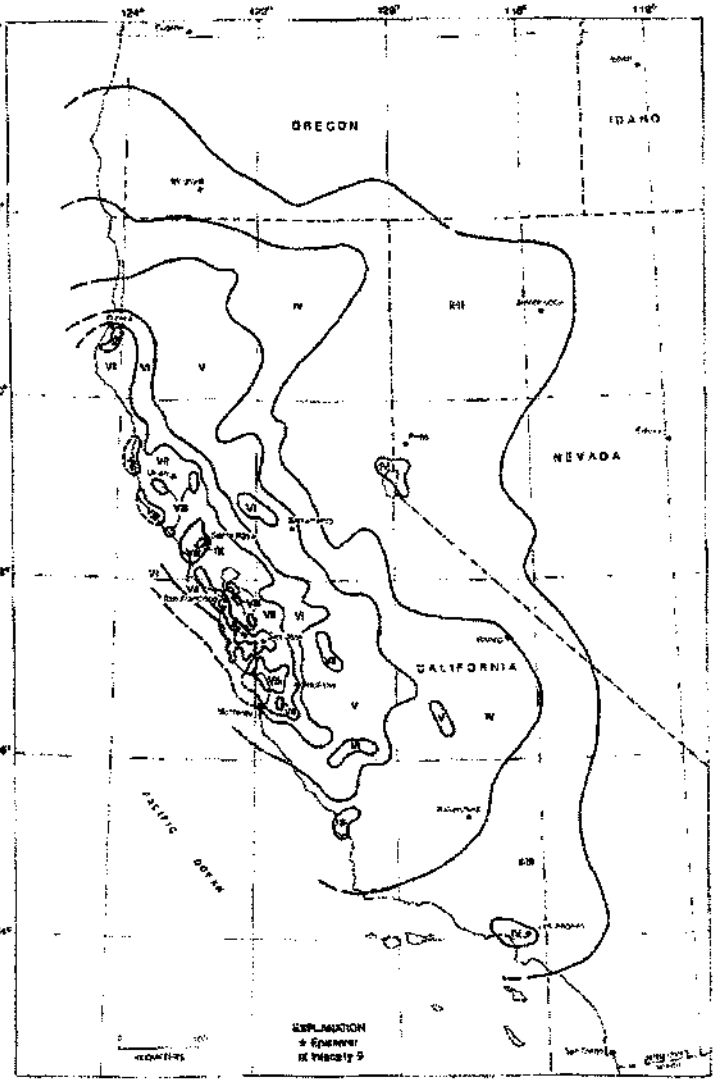
The table in Appendix B relating the PGA to the Modified Mercalli scale is taken from Munich Re's publication "World Map of Natural Hazards". Using this and the attenuation selected we can estimate the isoseismals of an event of known epicentral intensity.

Swiss Re's "Seismicity" report lists observations of several hundred histrical earthquakes. By collecting the estimated Richter magnitudes of these events with the Modified Mercalli intensities observed at various difference from the epicentre we can try to validate a generic attenuation function should we decide to use one. This is shown in Appendix C.

Actual attenuation functions depend on a range of factors in particular the local geology and geography, such as the presence of rivers or mountains. Therefore one should be wary of using a generic attenuation function that is applied to all territories.

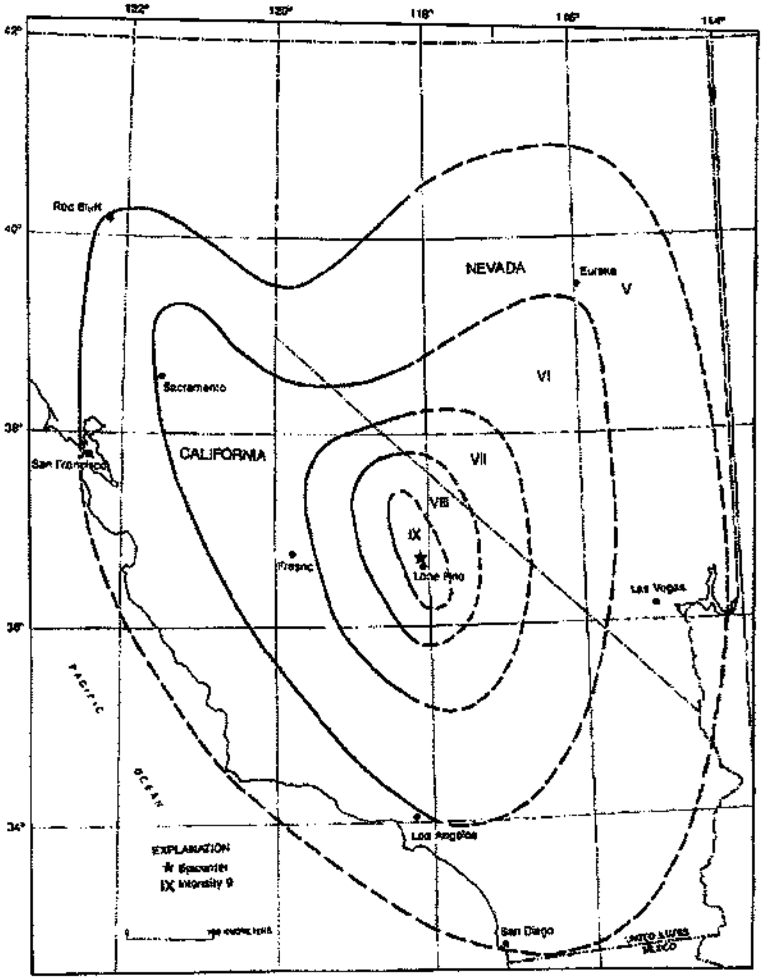
In the isoseismal map shown above the isoseismals were approximately circular. However, consider the isoseismals for the 1906 San Francisco quake shown below. The length of rupture for this quake is estimated to be 400Km.

This indicates that a model which assumes circularity of isoseismals is not always suitable. In this case the attenuation appears to be affected by the Sierra Nevada mountain range, but is also affected by the tectonic faults in the area.
So, instead of using circular isoseismals we can modify the model to produce elliptical or sausage-shaped, isoseismals by taking into account the length of the rupture.



Source:http://wwwneic.cr.usgs.gov/neis/eqlists/USA/1906_04_18_iso.html

The isoseismal map below also shows clearly the elliptical nature of the isoseismals due to the length of the rupture.



Source: **http://gldss7.cr.usgs.gov/neis/eqlists/USA/1872_03_26_iso.html**

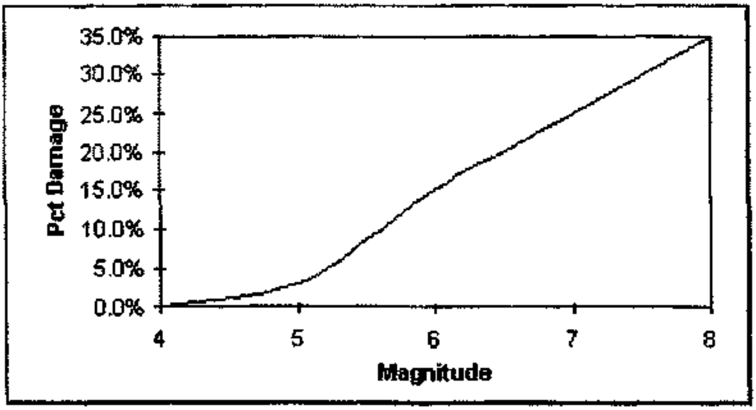
(iii) Damage % as a function of MM intensity.

Using the above we can estimate the areas affected at various levels of MM intensity by an event of a given epicentral magnitude. We now need to convert the MM intensity into an amount of ground-up damage.
The conversion is done using what we will call a damage function. Damage functions are also known as fragility or vulnerability curves.

We have found the following sources of damage functions, or information that may enable approximate damage functions to be estimated:

- Munich Re's "World Atlas of Map Hazards" which shows the percentage of damage as a function of MM intensity.

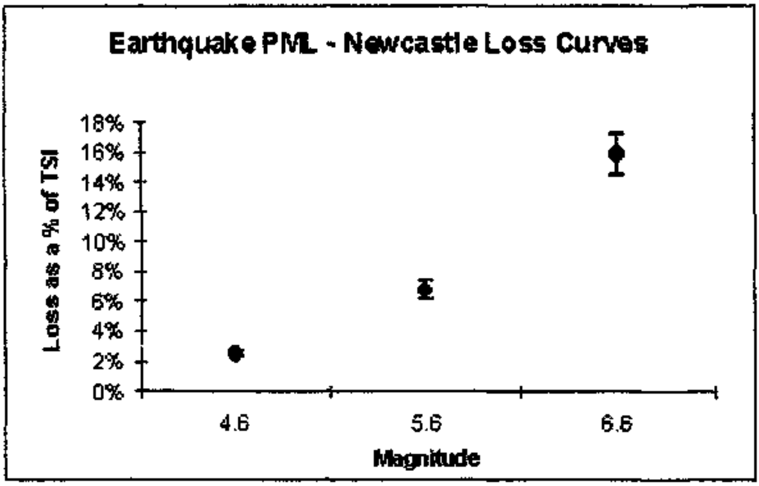
- Article by Arkwright Mutual Insurance Company on the earthquake hazard in the New Madrid Seismic Zone



Source: www.arkwright.com/about/news_room/bylines/9803sp_jor.htm

This shows the shake damage curve used in EQECAT's USQuake model for a certain type of building. Note that this webpage no longer exists at the site shown due to the merger of Arkwright with FM Mutual.

- Newcastle, Australia, Earthquake 1989 database. This is a database maintained by the Natural Hazard Research Centre of Macquire University.



Mean PML% showing variation (± 1 standard deviation)

Source: http://www.es.mq.edu.au/nhrc/nhqoct.htm

- ATC-13, "Earthquake Damage Evaluation Data for California", Applied Technology Council 1985. This is the seminal report on damage caused by earthquakes. It is believed to be the basis of the damage curves used in many Cat models. See references for details of how to obtain this report.

- USGS: Steinbrugge's : Analysis of Loma Prieta with emphasis on loss estimation.

- It is also possible to derive damage curves from some some Cat models. This can be done by finding a small zone and placing a unit of exposure in that zone. For example, San Francisco county is relatively small so the effects of attenuation will be relatively small within the county. By running various events of known intensity against that exposure you obtain the amount of damage as a percentage of the exposure. This can be done for a range of event intensities to obtain the damage curve being used in the model. The location of the epicentre need to be considered, which does complicate this approach. For example,the damage suffered by an event of RM 7.0 with its epicentre in the county may have a similar level of damage as an event of RM 8.0 with its epicentre tens of kilometres away. It is also necessary to take into account whether the CAT model produces an estimate of ground-up damage, or produces the estimated damage above a certain level of policy deductible.

- http://www.abag.ca.gov/bayarea/eqmaps/shelpop/bldg.html. This page on the ABAG (Association of Bay Area Governments) website shows the numbers of residential properties made uninhabitable as a function of the type of construction, year of costruction and MM intensity. Although this is not the average damage amount, it may be useful as a cross-check on the damage function selected, or allow the relativities between damage curves based on these factors to be estimated.

The above damage curves are intended to apply to property losses. As mentioned in the introduction, we may also need to estimate the losses for other classes of business such as Workers Compensation. In such cases appropriate damage curves may need to be judgementally selected. Even though this would mean that the resulting model is not as objective as one may wish, it may be preferable to have a model, such as one of the type we are attempting to describe here, in which the assumptions are made explicit, rather than a more simplistic approach such as the application of PML%s.

There are many references to earthquake damage on the Internet. Earthquake engineers have done a great deal of research into the subject. However, their emphasis is different to that of an insurer. Engineering research quantifies the amount of damage in a different way to the cost of repair. Engineers are often trying to identify the reasons that structures fail so that designs can be changed to avoid similar structural failures in future. Despite scouring many papers published on the Internet we did not find any that could have been useful for our purpose here.

(iv) Variability of % damage within isoseismals

The amount of damage as a percentage of the insured value within a region that suffers a given level of shaking intensity will vary considerably for a variety of reasons, such as:

- Different properties will have different fundamental periods and will respond differently to the frequencies of seismic waves. This is because different buildings have different resonant frequencies. Seismic waves have a range of frequencies within them. This is what is meant by the spectrum. Building will be sensitive to those component frequencies which match, or are harmonic to, the building's own resonant frequency. See http://nceer.eng.buffalo.edu/faqs/eqaffect.html for a good explanation of this.

- Properties will have been constructed differently, so will have varying degrees of asymmetry in their designs. Asymmetry can accentuate damage as different parts of the building resonate at different frequencies.

- Properties will have been built to different standards, different building codes, with differing degrees of intentional anti-seismic features, and may or may not have been retro-fitted with antiseismic features.

- The hazardousness of the occupacy will vary

- The size of the property will affect the ratio of damage to insured value.

- There may be very localised subterranean factors that affect the response to the seismic shaking.

- Properties may be affected by the performance of neighbouring properties e.g. by pounding.

In a given part of the area affected it is possible that some properties will be constructive total losses yet nearby properties may be hardly damaged at all.

We have not been able to find any information about the distribution of damage ratios for a given level of shaking intensity. This is not surprising given the difficulty in obtaining damage ratios for a given level of shaking intensity. An abstract of one earthquake engineering paper did suggest that the damage to properties affected by the same intensity was thought to be Lognormally distributed.

It is therefore left to the actuary's judgement to estimate a suitable level of variation around the mean damage ratio selected. Similarly, it is left to the actuary's judgement to select a suitable family of distribution functions to model the distribution around the mean.

(v) Return Periods

As mentioned above, this topic was covered elsewhere in the actuarial literature.

We have not been able to find a definitive list of return periods by location. It is unlikely that such a list exists for a variety of reasons. Some data on historical quake magnitutes is available from the USGS website (see above). Also, major quake experience is summarised in the CRESTA manual and is available in databases such as AXCO's.

The Gutenberg-Richter relationship has the following form:

Proportion of quakes with magnitude = $a * 10^{-bM}$

where, a is a scaling constant. The value of b changes from region to region, but the average worldwide value is approximately 1.

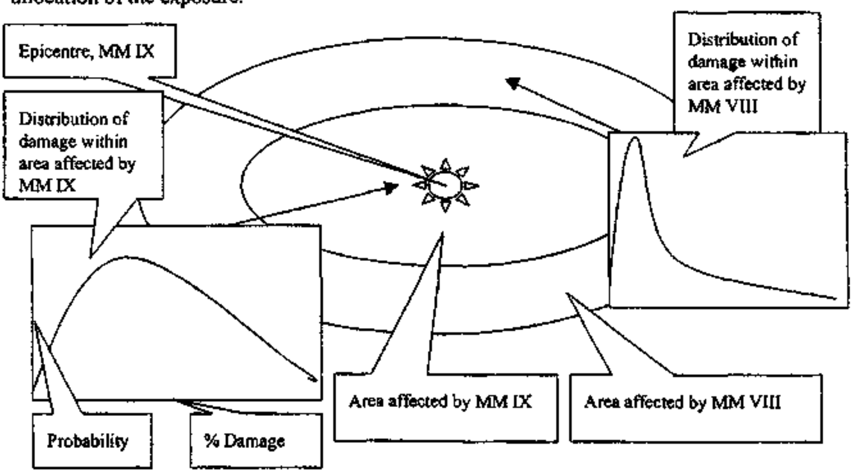
(vi) Exposure base

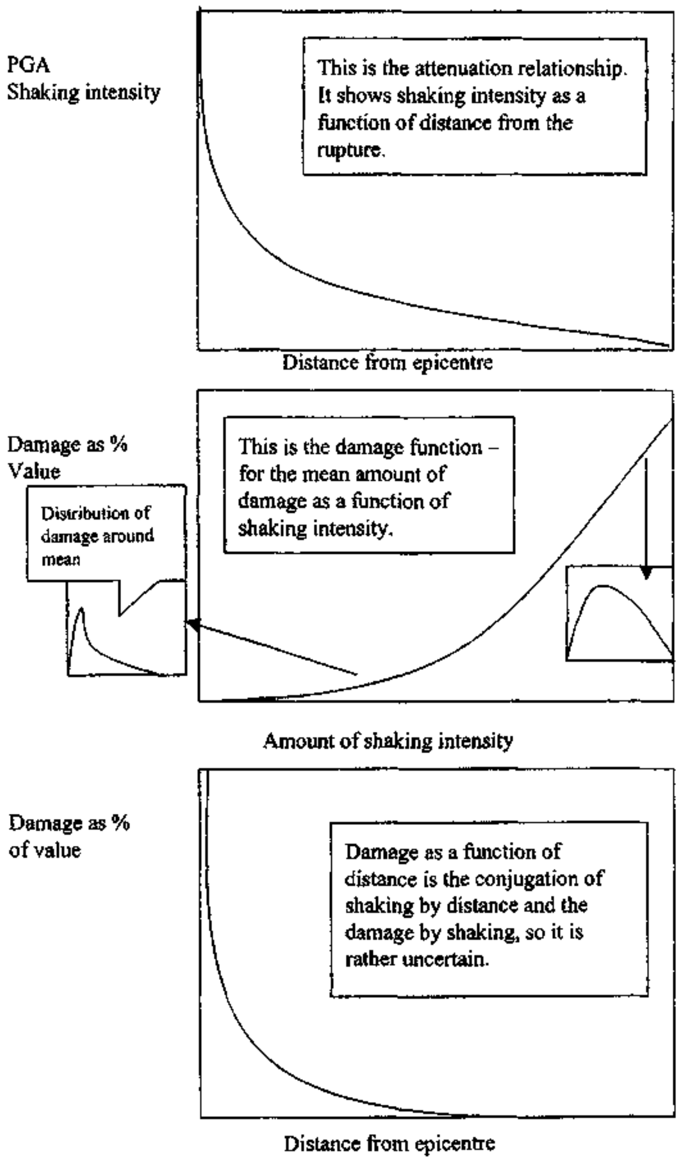
The model described above allows us to estimate the mean amount of damage caused to all properties within the rings which make up the isoseismals. We have even estimated the distribution around the mean amount of damage. All that we now require is the exposure base that we will apply this amount of damage to.

This is not as simple as it may sound.

For one thing, the location of the epicentre is uncertain.
For another, as a reinsurer we may not know the precise location of the properties we are exposed to.

The diagrams below indicates the status of the model before we consider the allocation of the exposure:

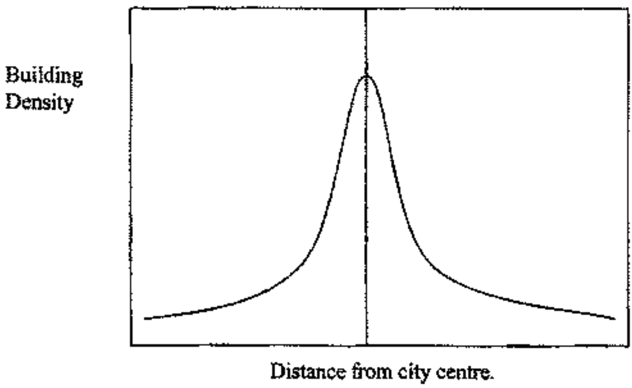



PGA
Shaking intensity
This is the attenuation relationship. It shows shaking intensity as a function of distance from the rupture.
Distance from epicentre
Damage as %
Value
Distribution of damage around mean
This is the damage function – for the mean amount of damage as a function of shaking intensity.
Amount of shaking intensity
Damage as %
of value
Damage as a function of distance is the conjugation of shaking by distance and the damage by shaking, so it is rather uncertain.
Distance from epicentre

The above curve allows us to estimate the mean damage in the isoseismal band around the epicentre. How we allocate the exposure will further exacerbate the level of uncertainty.

In practice we tend to find the major aggregations of risk in the major cities. A typical city may have a central area of office and commercial buildings, surrounded by a ring of residential suburbs. Industrial complexes may tend to be located either on the outskirts of cities or on industrial parks.

Let us say that we can represent out exposure in a particular region graphically as show below:

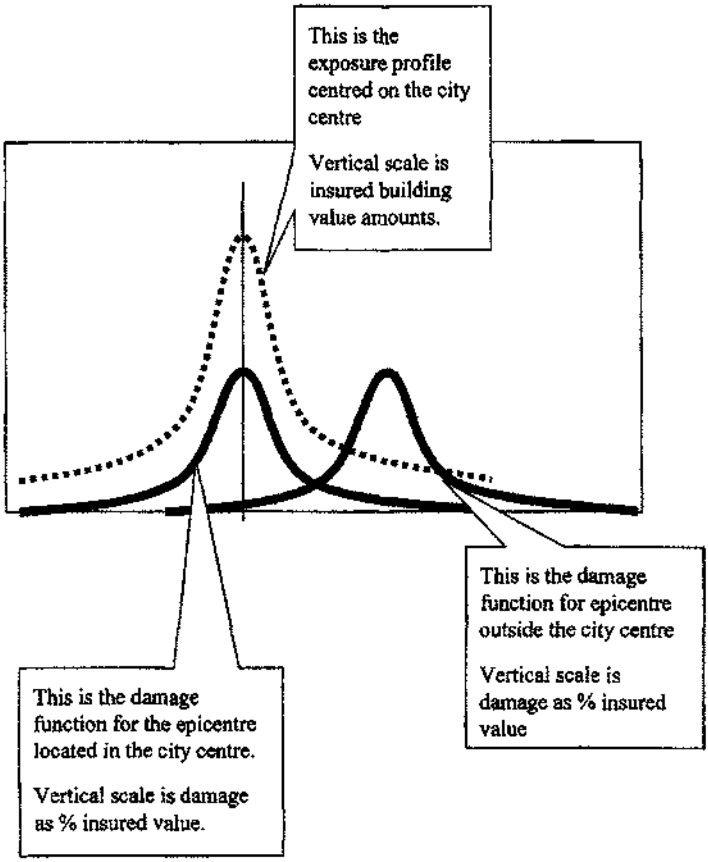


This is intended to represent an exposure to a particular city, with a concentration in the centre, petering out into the countryside.

Clearly, the maximum amount of damage will occur if the epicentre of the PML event is at the centre of the city, where there is the highest concentration of exposure.

As the exposure distribution is major additional element in the model it is suggested that we assume that the quake is epicentral to centre of the exposure. We can allow for this in our choice of return period. That is, we will choose a PML return period for the event which is effectively epicentral to the centre of the city.

The above graphs illustrate the importance of the location of the epicentre. A minor quake centred on the peak exposure base may cause as much damage as a major quake epicentred several kilometres away as shown on the graphic below.


This is the exposure profile centred on the city centre
Vertical scale is insured building value amounts.
This is the damage function for the epicentre located in the city centre.
Vertical scale is damage as % insured value.
This is the damage function for epicentre outside the city centre
Vertical scale is damage as % insured value

To summarise: what we have shown is it is possible to construct a simple earthquake model.

We have shown how to model the MM intensity experienced in regions around the epicentre of an event of a given rupture length, depth and epicentral intensity. We have indicated how the intensity can then be converted into the amount of damage.

It would be relatively simple to convert such a deterministic model into a stochastic model by allowing the key parameters of location, rupture length, depth and intensity to vary. The resulting damage profiles could then be applied to the exposure profile in order to obtain a simulation of the potential experience.

By going through the steps involved we have tried to highlight some of the difficulties involved in calibrating each element. It can be seen from the final graphics that the amount of damage can be very sensitive to the actual location of the epicentre relative to the exposure base. For residential property this may be less of an issue as it tend to be fairly dispersed, especially in the US. However, there can be greater concentrations of value in industrial and commercial property.

We have concentrated in the paper on earthquake modelling. The final section briefly discusses how a Tropical Cyclone model could be produced.

8b Tropical Cyclone Model

In this section we consider a situation where an actuary may need to do some degree of catastrophe modelling but an off-the-shelf model is not appropriate due to cost or materiality constraints.

For example, as part of a larger portfolio an insurer writes a policy covering all yachts in a particular marina against perils which include windstorm. The insurer may wish to evaluate the value for money of reinsurance protection offered on such a risk.

Such a *single site/ specific hazard analysis* may benefit from a working knowledge of catastrophe modelling. Traditional burning cost methods are of limited use for such investigations with little or no historic data.

The simplest approach would be to apply an a return period to the EML.

Expected Loss = EML / {Return Period}

Giving an expected annual loss for a given insurer for a given event in a given location.

We may choose how detailed we want the model to be, depending on the data available and the materiality of the task at hand.

Simple Specification

Again, the simplest investigation involves a single site and a specific hazard e.g. a hurricane of known intensity at a known location.

At the very least, such an approach enables us to measure the impact of various scenarios on our revenue account. Monte Carlo methods could later be used to arrive at an expected loss for all possible events.

Return Period : at the simplest level, a return period function may be derived from two data points (relating hurricane intensity and return period) and an assumption of an exponential relationship between the two.

If we are only interested in a certain region, then the historic experience for that region is probably the best source of data.

Intensity : The intensity of a hurricane is usually measured by the Saffir Simpson scale. The intensity depends on the maximum windspeed attained within the system and a mathematical description of how windspeed varies from the eye to the edge. This second parameter is often referred to as attenuation.

We could assume that intensity drops off linearly with distance from the eye. The only data we require is the distance beyond which the influence of a an intensity x hurricane ends.

In fact, windspeeds in the eye of a hurricane are relatively low. As one moves from the eye out to the edge of a hurricane, windspeeds peak at a particular radius before falling off as the edge is approached. Many models of hurricane attenuation are available e.g. Depperman (1947), Holland (1980) and De Maria (1992).

Damage : The next step in the process is to convert the intensity into a measure of damage. As a rule of thumb, damage increases with the square of intensity (Emanuel - Anthropogenic effects on tropical cyclone activity).

The more formal mechanism for converting from intensity to damage is by means of a Damage Curve, also known as a Loss Curve. This curve simply describes the relationship between intensity an damage. Several are described in publicly available literature e.g. 'Munich Re's World Map of Natural Hazards' has a loss curve for property damage.

EML : The portfolio EML is simply the sum of EMLs of all risks in the site in question

Reinsurance : Allowance needs to be made for reinsurance programmes in and out.

Less Trivial Specification

One example of a more sophisticated way of modelling a windfield is be means of the Rankine Vortex. The windspeed V at radis r from the eye (denoted V(r)) may be defined as:

$$V(r) = \begin{cases} V_{max} \times \frac{R}{R_{max}} \; If R < R_{max} \\ V_{max} \times (\frac{R_{max}}{R})^x \; Otherwise \end{cases}$$

$R_{max} = RadiusOfMaximumWindspeed$

$V_{max} = Windspeed@R_{max}$

$0 < x < 1$

And x is used to calibrate the model. Typically x = ½. This model is limited by the fact that Rmax and Vmax must be known but it does model the phenomenon reasonably well It does have a tendency to overestimate velocities near the edges of a hurricane.

Appendix A: PML% applicable to Californian primary property

	Type	Ded'ble	California Department of Insurance zones					
			A	B	C	D	E	F,G,H
1a/b	Small residential	1	5.4	4.6	4.9	5.2	4.2	2.5
	Homeowners	5	2.9	2.4	2.5	2.4	1.9	1.5
	business	10	1.7	1.4	1.4	1.3	0.9	0.9
1c	Wood + masonry	5	3					
1d		5	10					
	Mobile Homes	2	5					
2a	All-metal	5	2					
2b		5	10					
3a	Steel frame	5	15					
3b		5	25					
3c		10	25					
4a	Concrete	5	20					
4b		5	35					
4c		10	50					
4d		10	45					
5a	Mixed material	5	25					
5b		10	60					
5c		10	75					
6	Anti-seismic	5	10					
7	Miscellaneous	0	50					

Source: An Analysis of Potential Insured Earthquake Losses from Questionnaires Submitted by Property/Casualty Insurers in California, 1995-6, California Department of Insurance.

Appendix B: Modified Mercalli, approximately equivalent Richter Magnitudes and descriptions

Epicentral MM	PGA as %g	RM (approx)	Description (from USGS)
V	1 - 2	4.5 - 4.8	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	2 - 5	4.9 – 5.5	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	5 - 10	5.6 – 6.1	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken
VIII	10 - 20	6.2 - 6.8	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned
IX	20 - 50	6.9 - 7.4	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	50 - 100	7.5 - 7.9	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent
XI	100 - 200	8.0 - 8.4	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly
XII	> 200	8.5 and above	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Note that there is no strict correlation between MM and RM. MM takes into account factors like local soil conditions and the underlying geology. So, two events with the same RM could have rather different epicentral MM intensities. Furthermore, the RM is a single measure of the event intensity, whereas a single event would have different regions affected by different MM intensities.

The PGAs as % gravity are taken from Munich Re's World Map of Natural Hazards.

<u>Appendix C: table of MM intensity by distance from epicentral RM in Km</u>

	0	50	100	150	200	250	300	350	400	450	500	550
RM	50	100	150	200	250	300	350	400	450	500	550	600
6.0	VII											
6.1												
6.2												
6.3												
6.4												
6.5												
6.6												
6.7	VII											
6.8												
6.9						V						
7.0	VII					VI						
7.1			VIII									
7.2												
7.3	VIII	VIII	V			V			IV	III		
7.4	VIII	VII										
7.5	VIII					VI				V		
7.6				VII								
7.7	X	VIII		VIII						IV		
7.8												
7.9								VI				
8.0			VII				VIII	VII		VI		
8.1												
8.2												
8.3												
8.4										VI		
8.5					IX							
8.6												
8.7	X					VIII		VII				VI
8.8												
8.9												
9.0												

Source: based on Swiss Re's Seismicity

Reading, web sites and references

General

Casualty Actuarial Society at www.casact.org
A very useful starting point with lots of downloadable actuarial papers, slides, discussion threads etc..
Why isn't the Institute's website anything like as useful as this?

NAIC Research Library, Disaster Insurance at www.naic.org/products/libr/sub21.htm
Various on-line or orderable articles on the subject (about 100 from 1994-present).

General Re's Research page at www.clough.com/GRN.nsf/Doc/researchcat
This has links to many other sites that may have more information. There is also the Cat modelling group at www.clough.com/CLOUGH.nsf/Doc/catmodelgroup

Earthquakes

An Analysis of Potential InsuredEarthquake Losses from Questionnaires submitted by Property/Casualty insurers in California 1995-6.
California Department of Insurance
Some useful background to the Californian earthquake insurance market and other more general issues.

Www.wsspc.org/summit/eqiperspectives5.html
Some papers which outline the modelling approach of several Cat modellers. Useful information on the considerations underlying the models.

Www.es.mq.edu.au/nhrc
Natural Hazards Research Centre
Links to other sites, various articles on the topic.This is research body funded by various organisations including QBE Insurance, Swiss Re Australia, Benfield Greig Australia and Guy Carpenter

wwwneic.cr.usgs.gov

National Earthquake Information Center of the US Geological Survey

www.eeri.org/EQ_basics/INS/INS3.html
Earthquake engineering Research Institute

nceer.eng.buffalo.edu

Multidisciplinary Centre for Earthquake Engineering Research:

www.atcouncil.org

Applied Technology Council - for ATC-13 damage analysis at 555 Twin Dolphin Drive, Suite 55-0, Redwood City, CA 94065 Tel. 415-595-1542

"Dwelling and mobile home monetary losses due to 1989 Loma Prieta, California, Earthquake with an emphasis on loss estimation", Steinbrugge & Roth at USGS, Box 25046, MS 967, Denver Federal Center, Denver, CO 80225. Tel 303-273-8500

www.geophys.washington.edu/seismosurfing.html

A page with lots of links to other sites, especially ones with original seismic data or seismic research information.

www.scec.org

Southern California Earthquake Center

Hurricanes

US House of representatives at www.house.gov/banking/

There are several written statements of various parties interested in HR219 and other disaster related bills These discuss the pros and cons of having a federal disaster insurance scheme.

Typhoon.atmos.colostate.edu/forecasts

Forecast of hurricane activity in the forthcoming season, by Gray, Lansea. Mielke and Berry.