PREDICTION OF INSURANCE LOSS FROM EARTHQUAKES

G R Walker[1]

SUMMARY

This paper outlines the nature of catastrophe insurance and how developments in information technology are providing tools which overcome many of the problems associated historically with estimating the risk of insurance loss from major natural hazards. A brief description of earthquake loss prediction models is presented, some of their current shortcomings highlighted, and the major priorities for research discussed.

INSURANCE

The Nature Of Insurance

Risks are something every person and organisation lives with every day. Many of them carry financial consequences. Insurance is about protection from these financial consequences.

There are five different strategies for coping with the financial consequences of an event from which a person or organisation is at risk:

1) Absorb the costs if the risk eventuates, which is known as self insurance.

2) Reduce the risks by undertaking appropriate measures, which is known as mitigation;

3) Rely on the government or charity to meet the costs;

4) Declare bankruptcy, or emigrate to another country, and pass the costs on to those to whom one is in debt;

5) Share the costs with others at risk by creating a pool of funds to meet the costs, which is the basis of normal insurance;

The actual strategy adopted will depend on the nature of the risks and the financial situation, personality and culture of the person or organisation at risk and it may involve a combination of these.

In relatively wealthy societies, normal insurance has become one of the primary strategies for protection against financial loss from unpredictable events. For it to work the risk event must be insurable which essentially means that the risk must be relatively small in order to keep payments to the insurance fund (the premiums) affordable, must be assessable, and must occur at random amongst those at risk.

1 *Alexander Howden Reinsurance Brokers (Australia) Limited (Member)*

Insurance operates best when a large number of persons or organisations are independently at risk from financial risks which, while large for the individual person or organisation, are small relative to the total premiums paid annually by the subscribers. Fire and motor vehicle property insurance fit well in to this category. Under these conditions, as a result of the central limit theorem, annual total losses tend to be relatively predictable, enabling the fund to be operated with a high degree of security in respect of ability to honour commitments to subscribers suffering financial loss from an insured risk. Also, since the number of individual events per year is generally relatively large, it is possible to undertake detailed analysis of them and thus rate individual risks according to the probabilities associated with their occurrence and size of loss. In this way the sharing of risk can be made more equitable by keeping it to those at equal risk, and those in high risk groups can be given an incentive to lessen their risk by mitigation measures.

Insurance works less well when, although the occurrence risks are small, the individual risks are not independent and are subject to aggregation if a risk event occurs. This is the situation that commonly occurs with damage from large natural hazards such as earthquakes. In an earthquake, many properties can be at risk from the one event leading to an aggregation of losses. The greater the potential for aggregation the more difficult it is to ensure the security of the insurance fund, even if the individual risk remains unchanged.

The Catastrophe Insurance Problem

Insurance to cover situations where aggregation can occur is generally called catastrophe insurance. Catastrophe insurance requires a different approach than normal fire insurance. Suppose the risk of damage to a particular property from fire is 1 in 1000 over a year, and that if a fire occurs the damage cost averages $50,000 per property with a standard deviation of $30,000. In a population of 100,000 properties it could be expected that about 100 properties would be damaged by fire a year since the occurrence for each property at risk is independent, and the fund can expect to pay out an average of $5,000,000 per year, with a standard deviation of about $500,000, for fire damage. By charging a premium of about

$75 per year the fund could be expected to cover losses, overheads and profits, and the establishment of some reserves for a bad year, with a reasonably high level of confidence.

Suppose the properties are equally divided between 10 communities each at risk from an earthquake on average once in a thousand years, so that on average a community will be hit every 100 years. If the individual property damage cost averages $50,000 over all the buildings experiencing an earthquake, with a standard deviation of $30,000, the individual property risk from earthquake will be the same as for fire. However the fund is now faced with paying out on average $500,000,000 once in a hundred years. The variance in individual costs will be partly due to variability of resistance and partly due to variability of magnitude of the event. The latter component will not be subject to reduction due the central limit theorem so that if the two effects contribute equally to the individual variance the standard deviation of the payout could be of the order of $250,000,000 There is a one percent probability that a community could be hit in the next year. How satisfactory would a $75 per year premium be now when this would only produce a pool of $7,500,000 per year. Who would pay the losses if an earthquake occurred in the next few years - the next fifty years for that matter. If this was the only option it would be regarded as an uninsurable risk. This simple example highlights the problem of catastrophe insurance and why insurers are wary of insuring for earthquakes, even in apparently low risk countries such as Australia, if there is a large accumulation.

Reinsurance

To make the situation above insurable the risk has to be spread more widely. This could be achieved by the fund only accepting a proportion of the risk, and/or reducing the number of properties insured in any single community at risk, and/or spreading its risk to other communities of similar risk. Alternatively it could lay off a proportion of the risk with other funds with more widely scattered risks. All these approaches are commonly employed. The latter approach is known as reinsurance. Generally the smaller a fund, and the more confined it is in terms of the number of communities it covers, the more reliance it must place on reinsurance. Because of Australia's relatively small population and its high concentration in a few major cities, Australian insurance companies are large buyers of reinsurance.

Reinsurance is generally provided by separate funds reserved for this purpose. One of the most well known centres of this activity is Lloyds in London which is home to several hundred separate reinsurance funds. There are also a number of well established specialist reinsurance companies in Europe and North America of which some of the most well known are Munich Re, Swiss Re, Mercantile and General Re, General and Cologne Re and American Re. During recent years, a number of new reinsurance companies have been formed based in Bermuda. In Australia some of the larger insurance companies such as GIO, QBE (Sydney Re) and NRMA have reinsurance arms, and recently a new Australian based reinsurance company ReAC was established.

Although reinsurance spreads the risk, there are limits to the spread that can be obtained, and big events involving very large aggregations, such as occurred in Hurricane Andrew, can still impose big demands on the reinsurers. Reinsurers seek healthy rewards for taking on these commitments. The additional layer of activity also adds to the overhead costs. The result is that catastrophe insurance generally requires significantly higher premiums than normal insurance for the same risk level, and the greater the aggregation effect the higher the premiums need to be.

Recent Experience

For twenty years prior to 1987, total insurance losses from natural hazards fluctuated within the range between two billion and four billion US dollars in current value terms. Spread over the world wide industry this was not a great amount. The reinsurance industry was lulled into believing that this was normal. As a consequence, reinsurance rates were small relative to overall insurance premiums and reinsurance was regarded as a profitable business.

Since 1987 the situation has changed dramatically. From 1987 to 1992 annual insurance losses from natural disasters were only once below five billion US dollars, peaked at over twenty billion US dollars and averaged over ten billion US dollars. Hurricane Andrew alone caused insured losses exceeding fifteen billion US dollars. Since then the Northridge earthquake in January 1994 has given rise to insured losses which have exceeded eleven billion US dollars.

This sudden change in losses has had a big impact on the industry. Initially, the reinsurance industry absorbed the additional losses through its own reserves and an expectation that it would not persist - but persist it did. Reserves were used up, some major reinsurance sources such as Lloyds in London found themselves in major trouble, and reinsurance became much more expensive and harder to get with considerable consequences for premiums for insurance against major catastrophes such as earthquakes and tropical cyclones.

The experience has highlighted another difference between normal fire insurance and catastrophe insurance. This is the much lower technical knowledge and level of analysis of catastrophe risks compared with normal insurance risks such as fire. Because the causative events are rare, and are scattered amongst communities with different building standards and insurance practices, it is very difficult to build up extensive statistical data on which to base loss calculations and rating systems. Indeed because of the need to minimise overhead costs and the lack of pressure from reinsurers for such data, detailed information on the nature of losses from natural hazards was rarely collected and retained.

RISK ESTIMATION

Historical Approach

The traditional approach to estimation of insurance loss from natural hazards has been extrapolation from experience. If it has happened once, it could happen again, and may be a bit larger next time. If it has not happened, then the risk is lower than where it has happened.

Prior to 1989 an earthquake in Adelaide was considered the mayor earthquake insurance risk in Australia mainly because the only significant insurance loss from an earthquake prior to 1989 had occurred in Adelaide in 1954. The 1989 Newcastle earthquake changed this perception. With a magnitude of 5.6 on the Richter scale it was not a big earthquake by international standards, but with an insured loss of the order of a billion dollars, it exceeded Cyclone Tracy as the cause of the largest single insured loss from a natural hazard in Australian history. It sent shock waves through the insurance industry as risk managers wondered what the bill would have been if it had occurred in Sydney or Melbourne. Now most concern is directed towards the Newcastle-Sydney area.

The weakness of this approach is that extreme events are very rare and changes in the nature of communities with time are such that experience is no guide at all to future events in a particular community. Most catastrophic losses take the insurance industry and the community generally by surprise. This was true even in the recent Kobe earthquake in Japan, it being over a thousand years since Kobe had experienced a similar event.

Advances in technology and the pressures created by the large catastrophe insurance losses in recent years are causing the demise of this traditional approach and the estimation and management of catastrophe losses is becoming much more of a science than previously.

Scientific Approach

Modern scientific approaches to PML estimation have their origins in an approach pioneered over twenty years ago by Dr. Don Friedman [4] from Travellers Insurance Company in the United States. This approach is based on simulating the occurrence of a hazard of specified magnitude in a particular location on a computer using maps of the insurance exposure. In his early studies, Friedman used either the characteristics of actual historical extreme events or postulated extreme events. Today the most sophisticated studies randomly simulate the events based on the estimated statistical characteristics of their occurrence in the particular locality [3].

The main elements of the technique are:

1. Estimation of the physical characteristics of the extreme hazard in terms of risk of occurrence - the occurrence model;
2. Mapping the relevant hazard parameters on the computer - the hazard model;
3. Superimposing the characteristics of the insurance exposure - the portfolio model:
4. Estimating the relationship between insurance loss, relevant hazard parameters and the characteristics of insurance exposure - the vulnerability model;
5. Integrating the interaction between the hazard and exposure to produce an estimated total loss - the loss integration model.

This approach can be applied with various levels of sophistication. In respect of earthquake damage losses, at the simplest level it can be used to gain ball park estimates of credible maximum losses by superimposing estimated isoseismals for postulated extreme earthquakes on maps of the insurance exposure, and integrating the resulting loss from assumed average damage loss / earthquake intensity relationships. A more sophisticated approach is to randomly simulate on the computer hundreds of years of earthquake occurrences and calculate the losses for each occurrence to produce data that can be used to give estimated losses as a function of return period. With modern geographic information systems the effects of soil properties on local earthquake intensity can also be included.

Currently there are a number of organisations around the world, including New Zealand and Australia, offering these services on a commercial basis.

EARTHQUAKE LOSS MODELS

Occurrence Models

The occurrence of earthquakes can be characterised in terms of the variability of magnitude, depth and type of fault movement within a region. Occurrence modelling is difficult for earthquakes because they may occur anywhere and without any limit on their magnitude - it being only the frequency that appears to change from one region to another - but in any particular locality, apart from the most active regions, they are generally very rare events. Consequently there is often only very sparse information available. Although their occurrence is generally related to faults, in most parts of the world full knowledge of potentially active faults is not available.

In Australia, the comparatively low level of earthquake activity and the short period of historical records makes occurrence modelling extremely difficult and the associated reliability is probably very poor. As a consequence it is common to use simulations of postulated earthquakes based on past events rather than Monte Carlo models.

Away from the most active regions, occurrence modelling is a major source of uncertainty. The largest improvements in occurrence modelling are likely to come from improvements in knowledge and modelling of the behaviour of the earth's crust, including both interplate and intraplate tectonics, rather than direct analysis of earthquake records, the latter being used more for calibration purposes.

Intensity Modelling

Modelling the pattern of ground motion intensity generated by earthquakes, often expressed as isoseismals in terms of the Modified Mercalli scale, is reasonably well developed, particularly in areas of relatively common seismic activity. The two major factors are attenuation away from the source and the effect of different soil conditions. Attenuation, in some areas at least, appears to be dependent on the direction of faults. Although the effects of amplification of soft soils has been well demonstrated in earthquakes, predictions of the amount of amplification still appear to often underestimate it.

In Kobe large differences in intensity were to be found within a few hundred metres as a result of different ground conditions and their dynamic effect on buildings. Isoseismals on their own are limited as measures of the damaging characteristics of the ground motion. Ideally intensity modelling should produce estimated spectra of ground motion together with peak ground acceleration and velocity, as this is the basis of structural design. This is likely to be the area of the most significant improvements in intensity modelling.

Vulnerability Models

Vulnerability modelling involves classifying the insured risk into categories which can be both readily identified and are likely to have different vulnerabilities, and then determining a relationship between likely insurance loss and the ground motion intensity for each category. Typically categorisation would differentiate between the type of insured risk - ie building, contents, or business interruption - the form of construction - eg house, office building, factory, shop, etc - the type of construction - eg moment frame, shear wall, brick veneer, etc - materials of construction - e.g. heavy steel, light steel, reinforced concrete, unreinforced masonry, etc - and other factors such as age and height.

Vulnerability modelling is one of the least developed areas of rational insurance risk assessment. This is largely due to the lack of useful historical information on insurance losses. Traditionally insurance companies have only retained information on overall losses from an event. Because of the cost of recording and analysing data in the pre-computer age, and the pressures on the industry following a major disaster, the details of losses from major hazards in terms of individual policies were generally poorly recorded and managed, and were often lost within a short period of time. As a result, it is not possible to simulate the isoseismals of historical events and analyse the vulnerability in terms of the categorisation described above. It is only in very recent events such as the Loma Prieta earthquake and the Northridge earthquake in the United States that detailed analyses have been made, largely as a result of the influence of the development of insurance risk modelling. Most of this has been undertaken as a proprietary activity to gain commercial advantage and little of it is available publicly.

Insurance loss is related to damage and there is some information available on damage as a function of earthquake intensity in the literature [2] which can be used as a starting point. In Australia some useful information was obtained from the Newcastle earthquake by individual insurance companies [6].

Shortcomings in vulnerability modelling were probably the principal reason for the poor predictions of total insured loss made by most models following the Northridge earthquake in Los Angeles. The general consensus from models indicated final losses of the order of 1.5-2.5 billion US dollars, but the actual insured loss at the latest report was over 11 billion US dollars, by far the most expensive insurance loss from a single earthquake in history.

The development of rational vulnerability models is one of the big current structural engineering challenges. Structural reliability theory is reasonably well advanced, but it has been primarily developed in terms of identifying the boundary between failure and no failure of a component or system. Statistical modelling of the financial consequences of structural failure has not been part of this approach to date. This is what is needed to underpin the development of rational vulnerability models. Instead of just focusing on the point of failure, structural models are required that look at the consequences of failure, especially the financial ones, including business interruption. It should be possible to develop vulnerability models based on such an approach which can be calibrated against observed losses. Such models should prove much more reliable than the empirical models currently used, especially in regards to portability from one region to another.

Loss Integration Models

The loss integration models are basically geographic information system (GIS) models on which the isoseismals, the insurance portfolio and the vulnerability information can be modelled and integrated to produce estimates of overall loss. One of the issues associated with these models is the fineness with which the information should be modelled. Various levels are used. Post codes are commonly used in Australia because insurance portfolio information tends to be kept in this form, but it has its limitations as soil conditions often vary significantly within a post code. Ideally the location of each building should be modelled - ie geocoded and treated individually. The most sophisticated models can be expected to increasingly adopt this approach as electronic recording of policy information by companies improves.

A significant problem that has occurred with this aspect of the models is the level of confidence of the results. Different providers use different approaches. Some present losses in terms of the expected value, which will correspond approximately to the fifty percent confidence limit, others in terms of the ninety percent confidence limit, some both, and some just a so called 'conservative' answer. This can lead - and has done so - to widely differing results for the same situation.

MAJOR CURRENT ISSUES

The development of insurance risk modelling is part of the information technology revolution that is transforming the world's industry and commerce. It has only been made possible by the developments in computing enabling the storage and analysis of large quantities of information, and quick access to it. To date the modelling has been largely the initiative of hazard experts, generally engineers and scientists with a strong computing background, who have recognised the commercial possibilities from codifying their specialist knowledge into models and using the computer to integrate this information utilising geographic information systems. The commercial exploitation of these models has been greatly enhanced by the effects of Hurricanes Hugo and Andrew, and the Loma Prieta and Northridge earthquakes, which have highlighted the weaknesses of past approaches.

In the United States a number of organisations have been formed to offer these risk modelling services commercially. Among the most prominent of these are Risk Management Solutions (RMS), which uses a model initially developed by earthquake engineering researchers at Stanford University; EQE International which developed them initially as an extra service in the area of earthquake engineering in which they offer specialised services; and Applied Insurance Services (AIS), which began by offering commercial services in hurricane insurance risk modelling based on Don Friedman's approach. Each of these organisations now offers insurance risk modelling for a range of hazards in the United States, and are now setting their sights on offering similar services world wide.

In Australia and New Zealand there have been similar developments on a smaller scale, generally for one hazard only, and based around a single person or small group with specialist engineering or scientific expertise of the hazard.

One of the consequences of this strongly engineering and science background is that there is generally a relatively high level of sophistication in the modelling of the scientific aspects of the problem but a relatively low level of sophistication in the modelling of the damage and financial aspects, which are outside the general experience of engineers and scientists. There is also a tendency to present the results in engineering terms, not realising that the insurance culture is different. The major issues surrounding the use of these models largely derives from this situation.

Four significant issues that need to be addressed are:

- how to handle uncertainty
- how to get the best information from sparse past data
- how to get the best information from future events
- modelling of consequential losses.

Uncertainty

Despite its apparent pre-occupation with risk, the insurance industry has not developed a risk culture in dealing with natural hazards. Like the engineering profession it reduced the problem to a deterministic one, and developed a culture based on this approach. Structural engineers agreed on a design load and forgot the actual loads were statistically variable. Insurers agreed on a percentage of insured value as the 'probable maximum loss' and assumed it was the maximum possible loss. Over the past twenty years the structural engineering profession in moving to limit state design has begun to develop a probabilistic culture in respect of design. Until the advent of risk modelling the insurance industry had remained securely in its deterministic culture. As a consequence many in the insurance profession are finding it difficult to deal with the probabilistic nature of the outcomes from the risk models.

Part of the reason is that many are still looking for a single answer - the probable maximum loss - when there is no such thing. And part of the reason is the confusion of different presentations in terms of confidence limits described above. The latter is itself largely the consequence of engineering thinking. The primary interest of structural engineers is in ensuring that buildings do not fail within their lifetime, which is generally considered to be at least fifty years. This defines the minimum time frame for the problem. Because of this long time frame and the paramount importance of safety, engineers have adopted a conservative approach, erring on the safe side when in doubt. Design loads and design strength both tend to be specified in terms of the ninety five percent confidence limits, ensuring that the likelihood of failure in the lifetime of a building is generally very small.

By contrast the insurance industry operates on a one year time frame. The only real interest is the probability of loss in the coming year for which premiums must be set, and an overly conservative answer will be as bad as an unconservative answer if it makes the company uncompetitive. The insurance industry does not want two probabilistic pieces of information like they are given now - return period and confidence limit. Both are just elements of the overall uncertainty, one due to the scientific variability and the other to lack of knowledge. Engineers and scientists like to keep the two separate, but insurers want the risk expressed in terms of one probability term only - the overall risk, allowing for both scientific variability and lack of knowledge, of specified levels of loss being exceeded in the next year. They then need to develop methodologies of risk management to utilise this information effectively, but that is another story.

Sparse Historical Data

Currently there is a tendency in the development of the occurrence models to only use good data, which often means only data recorded in modern times, and to then assume that this data is representative of all time ignoring the basic non-stationarity of natural hazard occurrences, whether earthquakes or tropical cyclones. Earthquakes release stress and, in the medium term, a major earthquake will generally result in the reduction of risk from another major earthquake in the same area, once the aftershocks have settled down. How many sites of major earthquakes have been the sites of second major earthquakes within a hundred years? Much less, it is suspected, than would be expected assuming statistical independence with time. Yet most risk maps appear to assume this independence and often show the greatest risks where earthquakes have occurred in recent history.

The development of tectonic models of crustal deformation should help overcome this problem, but perhaps in the meantime there should be more study of long term records where they exist, even if the data is not good, to see what patterns, if any, can be observed over long time periods. A brief study of Japanese records [5] for instance suggests that Kobe had not experienced a similar earthquake in its vicinity since the 800's, and that in the Kansai region generally there have been periods of considerable earthquake activity separated by periods of relatively little activity.

In respect of the outcomes there is also value in comparing these with all the records of damage available for the region using a broad brush approach to see if they are in the same ball park. There can be a tendency to put more faith in the output of complex computer programs than can sometimes be justified.

The Next Event

The next major event in New Zealand or Australia is potentially the best source of data for improving, in the short term, the quality of the vulnerability models used to simulate the performance of construction in this region. The full potential, however, will only be realised if there is good planning before the event occurs. For generating information on vulnerability, major events need to be treated like major experimental projects such as sending up space shuttles. Such experiments need to be designed and tested well in advance because they are one-off opportunities.

How should these experiments be designed? There appears to be two fundamentally different approaches that can be adopted.

One is an essentially empirical approach along the lines traditionally used by the insurance industry for events such as fire and vehicle damage. In this approach an attempt is made to relate losses directly to the categories of buildings described above. As the information will probably not exist to categorise all risks in a portfolio, it will be necessary to undertake this on a sample basis. The sample needs to be designed in advance, and all the information on categorisation established before the event, so that at the time of the event efforts can be concentrated on recording the losses themselves, and their nature. Neural networks would appear to be a powerful tool for undertaking the analysis of the data from this approach [7].

The other approach would be to adopt the more scientific approach of developing models of the failure of buildings as a function of the hazard intensity - ground motion characteristics in the case of earthquakes - and the consequential economic losses, and use the occurrence of the event to calibrate these models. This would be a more fundamental research project, and again the design of the experiment would need to be in place before the event. In this case, the design would require a model to have been postulated, critical factors and variables to have been determined, a sample of appropriate buildings fitting the model to have been identified and a procedure established for observing the critical factors and recording the data.

The advantage of the first approach is that it is likely to provide the most useful data in the short term. However its limitation is that the information it produces will be limited to typical buildings in the area of impact. Because of the wide disparities been building practices and standards from one region to another, the information will be of limited universal value. The second approach has the advantage that it has the potential to develop universal information by using design strength as a characteristic variable, but it is an approach that will require much more detailed research. One of the problems associated with this approach is that the event itself cannot be programmed, making it difficult for instance to undertake it as a PhD project. This is a problem that needs to be addressed as this approach has the greatest potential in the long term. Ideally the two approaches should be undertaken in a complementary manner.

Consequential Losses

One of the areas of greatest uncertainty in estimating future losses is that of business interruption. The disruption caused by the Kobe earthquake has highlighted the potential there is for large losses of this nature in a major event [1]. In the past it has commonly been thought that business interruption would be directly related to the amount of damage, but this was not so in Kobe. In Kobe most of the modern buildings performed well with only minor damage to the building fabric. However most of these buildings were unable to be used for at least two months because of the damage to water and gas supplies, or because access was disrupted in the case of buildings on the artificial islands, or because staff could no longer live in the area due to damaged accommodation and the lack of public transport within Kobe due to damaged rail and road overhead structures. The business interruption costs to the owners would have been much greater than the building damage in many cases. In one case quoted [1], it was estimated to be fifty times higher. The entire operation of some of the major vehicle manufacturing plants had to be closed down because they were dependent on parts from small factories in Kobe working to 'just in time' schedules.

Fortunately for the insurance industry business interruption insurance is very rare in Japan, but this is not the case in New Zealand and Australia. Just what the insured losses from business interruption would be depends on the wording of the policy, but if a Kobe magnitude event occurs it is likely to be larger than anticipated. This is an aspect of vulnerability modelling that cannot wait until the next event. Using established simulations of likely damage it should be possible to study the business interruption costs that are likely to occur, but it will require interdisciplinary research involving both engineers and business economists.

THE FUTURE

The development of catastrophe insurance risk modelling can be expected to continue at a relatively rapid rate, until it is a standard feature within the insurance world. This will lead to a major change in the approach to insurance against natural hazards. Currently hazards are lumped together with other risks and standard rates and policies offered over large areas irrespective of differences in actual risk. These new tools have the potential to readily determine the individual risks associated with particular properties. This will result in policies and premiums tailored for individual properties. Competition will ensure that once the tools are available they will be used in this way, which will only be applying catastrophe insurance in the way that theft, fire and motor vehicle insurance have been applied for a long time. This will result in a more just system, with poor risks being faced with real incentives for mitigation, rather than being subsidised by the good risks as is the case at the moment.

Currently catastrophe insurance modelling is still in the early development phase. It is an area that offers exciting opportunities for research that will have high commercial value in the coming years.

REFERENCES

1 Alexander Howden Group Ltd, 1995. *The Great Hanshin Earthquake*. London.

2 Coburn, A and Spence, S, 1992. *Earthquake protection*. Wiley, Chichester, UK.

3 Dong, W, Wong F, Kim, J and Shah, H, 1988. A knowledge-based seismic risk evaluation system for the insurance and investment industries (IRAS). *Proceedings, 9th World Conference on Earthquake Engineering*, Tokyo.

4 Friedman, D G, 1975. *Computer Simulation of Natural Hazard Assessment*. Institute of Behavioural Science, University of Colorado, Boulder.

5 National Astronomical Observatory (Japan), 1994. *Chronological Scientific Tables*. 1994 Edition, Maruzen, Tokyo.

6 NRMA Insurance Ltd, 1990. *Newcastle Earthquake: the Unexpected Event*. Sydney.

7 Sandri, P and Mehta, K C, 1995. Using a Backpropagation Neural Network for Predicting ind induced Damage to Buildings. *Proceedings, 9th International Conference on Wind Engineering*, Delhi, 1989-1999.