PROGRESS IN EARTH SCIENCE RESEARCH OF BENEFIT TO THE EARTHQUAKE INSURANCE INDUSTRY

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Presented at the Conference on
INFORMATION NEEDS OF THE EARTHQUAKE INSURANCE INDUSTRY
held in Christchurch, November 1989

INTRODUCTION

For actuarial purposes and risk management it seems reasonable that the Earthquake Insurance Industry ask questions of the scientific community. Information on the temporal and spatial occurrence of earthquakes, on their size distribution, on variability about the mean occurrence values, and on the performance of engineering structures under earthquake loading are key requirements of the industry. However aspects of these areas of seismology, geology and engineering are known to different levels of confidence, and have differing potential for advancement, and each aspect has an interdependent but variable impact on final hazard evaluation.

In this paper we present an opinion of where scientific enquiry is headed and what impacts this new knowledge might have on the Earthquake Insurance Industry. We will endeavour to indicate what methodologies or areas of science might make a significant contribution rather than try to forecast particular findings. There is nothing more certain in science than the uncertainty of experiment and research.

IN WHAT WAY IS CURRENT RESEARCH THAT IS RELEVANT TO THE EARTHQUAKE INSURANCE INDUSTRY LIKELY TO DEVELOP?

Earth science research relevant to the Earthquake Insurance Industry is currently proceeding on diverse but interrelated fronts. The research is concerned with:

- the nature of earthquakes at their source;
- manifestations of past major earthquakes in the geological record, for example surface fault traces and uplifted coastal terraces;
- the propagation (including attenuation and sometimes enhancement) of earthquake waves away from source;
- studies of present-day ground deformations in response to stresses
- characterisation of near-surface materials and their response to seismic shaking;
- obtaining more accurate earthquake probability models.

These studies rely on the New Zealand networks of seismograph and strong motion recorders, detailed geological mapping and dating of deposits associated with surface fault movement, precise surveying of contemporary earth deformation, determination of geotechnical parameters of surficial geological deposits, and increasingly sophisticated computer modelling of the physical properties of the earth's crust, through which earthquake waves pass. Models and data developed by earth science studies, loosely embodied in the concept of earthquake hazard evaluation, are then used by the structural engineering profession for the development of seismic design.

A cornerstone of much earthquake research is the old adage that the "past is the key to the future". Dr Smith has, at this conference, pointed to the gap in present knowledge and the need for detailed studies of historical earthquakes in the period from 1855 to 1940. Although detailed knowledge about major earthquakes is only built-up infrequently (fortunately!) because of their sporadic occurrence, the on-going frequent occurrence of small earthquakes is a valuable data source to study the propagation of seismic waves and the physical nature of the earth's crust. This ability has been enhanced by the recent installation of digital seismographs which yield data suitable for modern computer analysis. In New Zealand, where the instrumental record of earthquakes extends back to only about 1940 on a national basis, and written records for only 150 years, the historical record of earthquakes cannot accurately convey the complete pattern of large earthquake occurrence. However there exists great potential to determine the occurrence of major earthquakes by unravelling the record

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preserved in surface fault traces and as uplifted coastal terraces. These studies are of particular importance in establishing nationwide evidence of large earthquake sources. For example, there have been very few historical earthquakes in the Central Otago region but geological evidence for active faulting is widespread. Geological evidence of large earthquakes is sometimes the only evidence of an earthquake hazard. For example, geological evidence for episodic uplift of old beaches along the east coast of the North Island indicate large earthquakes have occurred repeatedly along many parts of that coastline, whereas historic large magnitude earthquakes have only occurred in the Hawkes Bay area.

Assessment of seismic potential in a region is likely to advance when geological data on the behavioural characteristics of active faults in a region is combined with contemporary measurements of land deformations, and detailed seismological data. Utilisation of triangulation and precise levelling survey information has proven useful in assessing the current state of strain in regions, providing insights into the large earthquake cycle.

The ability to assess the impact of an earthquake at a site some distance from its source is advancing on several fronts, which is a major advantage, because it allows for cross-checking results obtained from independent methodologies. Ground motions from a single earthquake may be measured directly at many sites on strong-motion instruments, and depending on the siting of those instruments, on several different ground or building types. Relationships, in historic events, of shaking intensity with distance from source, size of earthquake and geological setting have been used to derive empirical methods of calculating ground motions. Geotechnical parameters of near surface deposits at sites of interest need to be known before the average ground motions derived by empirical formula can be applied to particular sites. Large variations in ground motions may occur at adjacent rock, deep alluvial and shallow alluvial sites. Recently developed, computer simulation of seismic wave propagation through geologic strata can incorporate the topographic variation into models of ground motion.

Methods by which primary earth science information, such as active fault recurrence intervals or frequency/magnitude relationships of earthquakes, are used in hazard estimates, especially probability estimates, are evolving rapidly. As recently as 10 years ago it was commonly believed that even if a major earthquake occurred today there was an equal chance of another occurring in the same place tomorrow. This idea quickly evolved into a mathematical formulation that suggests the probability of a major earthquake is constant in time and, for long recurrence intervals, the probability is simply the ratio of the period of interest to the average recurrence interval. Within the past 5 years it has been accepted that major active faults are sources of many major earthquakes. Fault rupture histories on many active faults have been shown to have some semblance of periodic activity. Therefore if active faults have a "memory", then the probability of future movement is conditional on the elapsed time since the last event. About 5 years ago there were suggestions that faults behaved in a truly characteristic fashion, with parts of faults (fault rupture segments) generating similar sized earthquakes with essentially constant repeat times. Since then, data from many active faults throughout the world have shown that the characteristic earthquake model is an over-simplification, although some elements of periodic behaviour are found on many faults. Another emerging view is of dependent behaviour between adjacent or nearby faults, resulting in temporal clustering of major earthquakes followed by long periods of quiescence. The northwest Nelson sequence of major earthquakes from 1929 to 1968 (and has the sequence finished?) may represent a New Zealand example of temporal clustering. These recent concepts complicate the probabilistic approach to earthquake hazard evaluation. For the time being, conditional probability models seem the most appropriate, but as more data on fault behaviour becomes available, increasingly complex mathematical models will be required to describe the real world.

WHAT ARE THE RELATIVE MERITS OF EARTHQUAKE PREDICTION, HAZARD ESTIMATION, AND RISK PREVENTION, AND WHERE IS PROGRESS MOST LIKELY TO BE MADE?

Long-term earthquake prediction (tens to hundreds of years) establishes the capability of a region or a fault to generate an earthquake of a particular size and this may be accompanied by an estimate of the probability that this event will occur within a specified time period. Geologically-based estimates of seismic hazard using conditional probabilities are increasingly endeavouring to make long-term forecasts of future activity. Substantial uncertainties surround these estimates at present but they serve a useful purpose in illustrating the potential for large earthquakes in presently quiescent regions. Shorter-term predictions (months to years precision) of future earthquakes are very topical but associated with large uncertainties. Whereas the results of long-term forecasting can be incorporated into engineering construction codes and urban planning schemes, shorter-term predictions are fraught with social implications. A complex administration structure is required to deal with short-term predictions.

Hazard estimation is particularly valuable to society. At various scales, hazard estimates illustrate regional and national variation, present information in terms of probabilities within time windows of interest, and can provide ground motion predictions at particular sites where engineers can incorporate them into seismic resistant design of structures.

Prevention of earthquake effects, that is the reduction of vulnerability to zero, would be highly desirable but is very difficult to achieve on a cost effective basis. One area of earthquake risk prevention that can reasonably be achieved however is avoidance of the hazard of fault rupture by not building across or in the immediate (c. 20 m) vicinity of active faults. Other aspects of the earthquake hazard can be mitigated to a level acceptable to the insurance industry in terms of economic loss, or to society in general in terms of threat to life and limb. In New Zealand this has been achieved in large part by design codes. Progress is possible in a number of areas of hazard estimation and mitigation and must be made, considering the unexpected levels of damage to industrial sites in the Bay of Plenty during the moderate - magnitude 2 March 1987, Edgecumbe earthquake. Hindsight tells us that the characteristics of earthquakes in that region are for stronger than usual near-source felt effects, probably as a result of the shallow focal depth of earthquakes and the soft, water saturated surficial deposits. In addition damage assessment in several of the industrial plants revealed inadequate seismic design, especially to areas of expansion in the plants.

WHAT ARE THE RESTRAINTS, BOTH ABSOLUTE AND FINANCIAL ON FUTURE RESEARCH

Some aspects of earthquake research depend on the on-going occurrence of earthquakes to build up a substantial data set. While small earthquakes are increasingly being able to be used for crustal studies and seismic wave propagation studies via computer analysis, it is the large earthquakes that are of most interest to the Earthquake Insurance Industry. There is some potential to learn more about large historical earthquakes but detailed characterisation of those events, to a standard considered acceptable today, cannot be achieved because of limitations in the observations made at the time. Rigorous scientific investigation of moderate and large earthquakes, when they occur, is of the utmost importance. Other aspects of earthquake research that have the potential to make an important contribution to refined hazard assessments, notably geological investigations of active faults and of surficial deposits, are relatively inexpensive, but are currently limited by opportunity and personnel in the tight science R & D climate in New Zealand. With both hindsight, and the assumption that scientific findings can be effectively translated into mitigation measures in construction, it can be asserted that a small investment in scientific investigation may well have halved the $250-300 million insurance bill in the Edgecumbe earthquake. Although these figures are open to discussion, we believe the cost effectiveness of carefully directed and timely scientific investigation can have this level of impact on hazard mitigation.

Computer-based earthquake research and modelling studies are heavily dependent on quality input data. In the seismological field this is improving with the installation of digital seismographs. There exists a wealth of historical triangulation survey data which has not yet been analysed but new surveys to compare them with, for deformation analysis, are very expensive. New technology, using satellite positioning systems, is beginning to offer alternative, competitively priced data, although the initial capital cost of satellite receivers is high. Some modelling work now feasible on seismic wave propagation and finite element analysis of crustal deformation require large capacity computers and involve lengthy CPU time. These studies would which also require major financial investment.

COULD FUTURE RESEARCH CAUSE A MAJOR RE-EVALUATION OF EARTHQUAKE HAZARD IN NEW ZEALAND ON EITHER A NATIONAL OR LOCAL/REGIONAL SCALE?

Current national evaluation of seismic hazard in New Zealand is based on historical seismicity and information obtained from active fault studies. With the exception of the lack of large earthquakes in central South Island along the Alpine Fault, and the occurrence of several large earthquakes in the northwest Nelson region in historical time, large earthquakes coincide with the most active faults. In other parts of the country active faults indicate the potential for future large earthquakes but with longer recurrence intervals. Therefore, on a national basis, it is expected that future scientific work will refine the assessment of future hazards but will not cause a major rethink. Perhaps the lack of earthquakes on the Alpine Fault will be recognised as a short-term gap in large earthquake occurrence as several workers have already suggested, and the northwest Nelson sequence may be recognised as temporal clustering of events.

On a local to regional scale we consider that substantial re-evaluation is possible and desirable. Already we recognise that ground conditions cause substantial variation in the intensity of ground motions. When these data are incorporated into hazard models, substantial changes and variation will be recognised on the local level. It is widely perceived that the earthquake hazard in Wellington is greater than elsewhere in the country. However, because of variability in local conditions and in building construction styles and standards, there probably exists as large a range of seismic vulnerability in Wellington as there is from North Cape to Bluff. As a digression, we suggest that a formula for equitable variable rating of earthquake insurance, particularly for the individual home-owner, needs to incorporate such variability.

Because so much basic geological study of active faults around New Zealand is still required, it seems likely that data from that work will suggest revision of present seismic hazard estimates on the local/regional scale. Such revision has recently occurred in the Eastern Bay of Plenty as a result of studies catalysed by the Edgecumbe Earthquake. In Northland, where no active faults are so far recognised, it is still possible that large earthquakes could occur. This would be surprising given our current understanding of the tectonics of the region but then large earthquakes have occurred in apparently stable parts of the Australian and North American continents in the past 100 years. This reminds us to resist the temptation to speculate on scientific results.

CONCLUSIONS

Current earth science research of value to the Earthquake Insurance Industry is proceeding in many diverse but interrelated fields. Studies on wave propagation, crustal structure, earthquake patterns, active fault histories, measurement of contemporary deformation, ground motions and numerical modelling all contribute to seismic hazard evaluation.

Hazard evaluation and mitigation strategies are more likely to be achieved and are generally more useful than short-term earthquake prediction.

Restraints on the pace of acquisition of new knowledge include the rarity of large earthquakes to study and unfortunate restrictions in R & D climate in New Zealand.

Re-evaluation of seismic hazard is not likely to change markedly on a national scale but is likely to be modified in many local/regional areas.