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EARTHQUAKE RISK IN AUSTRALIA

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Introduction to earthquake risk

Australia experiences relatively few earthquakes, and they are spread over a wide area, so earthquake hazard is quite low. Earthquakes are shallow, so very small events are often felt, moderate magnitude events can cause damage (in Newcastle in 1989 – see Figure 1), and large earthquakes produce surface ruptures.

Figure 1. Newcastle school damage (McCue, 1989).

Risk is measured in several ways, including casualties (injuries, fatalities) and dollars (repair or replacement costs, loss of income or business). Risk mitigation involves minimising these, or the average annual rate, or the maximum expected loss.

In Australia, the annual average casualties and damage rates are low, with most years giving zero or near-zero values, and the majority of the contribution from very infrequent large earthquakes. The maximum expected loss would be high for a large earthquake near a city, mainly due to the shallow earthquake depths and moderate risk criteria adopted for the building code. The 1989 Newcastle earthquake was only of magnitude 5.6, but caused 13 lost lives, with damage and loss of over 2 billion dollars. A less common (but not unexpected) magnitude 6.0 to 6.5 near a city will cause more casualties and damage, while an earthquake exceeding magnitude 7.0 near a city will be more devastating, but will be so rare that it will contribute less to the average annual loss rates.

Risk management depends on the relative weighting of casualties, and economic and environmental factors. The underlying risk philosophy is complex (whether to design to prevent collapse and thus minimise casualties, or to consider economic losses as well) and the analysis complicated (optimum expenditure on preparation, particularly building standards).

Almost all earthquake-resistant designs are based on a risk criterion, usually the earthquake ground motion that occurs on average once in a given return period. This return period may be specified by a loading code (traditionally 500 years), by a special purpose code (for dams it is often 10,000 years), or an optimum value computed by the risk analysis.

What can we do about it – risk mitigation

Earthquakes, like many natural hazards, cannot be prevented or avoided, but it is possible to minimise their effects. For many hazards, it is convenient to study the possible mitigation methods by considering past, present and future occurrences.

Past earthquakes

Our knowledge of hazards comes from past events, including the nature of the hazard, how we can quantify the hazard, and likely effects of the hazard. We can also learn about the recurrence rates (or average return periods), and how these vary for low, medium and high hazard events. It may be possible to estimate a maximum likely event at each location.

In active regions, such as California, very large earthquakes occur on average every one or two hundred years, and the building standards are based on the earthquake ground motion that occurs on average every 500 years. Structures built to this criterion should perform well for the maximum credible magnitudes.

The same 500-year risk criterion has traditionally been adopted in Australia. However, in relatively stable continental regions the 500-year earthquake is quite a small earthquake, only about magnitude 5.5, or about the same as the magnitude 5.4 Adelaide earthquake in 1954, or the magnitude 5.6 Newcastle earthquake in 1989. The 10,000-year earthquake in most regions will be of magnitude 6.0 to 6.5, and the 500,000-year (maximum credible) earthquake for most Australian cities will be of magnitude 7.0 to 7.5.

A magnitude 5.5 should normally cause little damage to designed structures (depending on how near the earthquake is), and this was the case in Adelaide and in Newcastle. A great deal of damage occurred to housing and commercial structures, especially older non-reinforced masonry.

A 500-year risk criterion for a building with a life of 50 years means that the design earthquake load will be exceeded during the life of the building with a probability of about 10%. There are about ten major cities and capitals in Australia and many other smaller cities, towns, ports, etc, so there is a good chance that design loads will be exceeded in a populated centre about every 50 years.

Present earthquakes

Preparation

Once the event has occurred, the crucial risk mitigation factor is the state of preparation. How soon help can be provided depends on the availability of appropriate supplies, trained voluntary or full-time emergency response people, and means of transport. A key aspect of preparation involves minimising bureaucratic red tape at the critical time. The most useful person after a natural hazard has occurred is one who knows what to expect, and has the resources to assist.

Help is usually required immediately after the event, but poor communication often provides a long delay. The response to the Haiti earthquake on 12 January 2010 was delayed for many hours by lack of communication. Because of the destruction caused by the earthquake, information flow was limited, and it was many hours until the first mention of possible fatalities was published in the media. In the chaos of Haiti, it would be almost impossible for anyone to have a reliable overview of the earthquake damage and casualties. However, it was known within minutes of the event that the earthquake was a large, shallow, probably strike-slip earthquake in a highly populated region with poor building standards. This may have been rapidly confirmed before nightfall by aerial surveillance from Guantanamo or the Dominican Republic (both within 300 km of the earthquake), but certainly at first light on the following morning. The catastrophic nature of this event should not have required confirmation from local reports, and the massive response effort could have started many hours earlier.

Warning

A warning occurs after the event has been initiated, and is provided to people who will be affected in time to allow mitigating actions (something has happened and it will soon affect you). Examples include flood warnings (e.g. there has been heavy rain in the catchment and the floodwater will reach you in 24 hours) or tsunami warnings (e.g. there has been a large shallow undersea earthquake, and it may have, or has, generated a tsunami that will reach you in eight hours).

Earthquake warnings are rarely possible because of the high speed of seismic waves, which travel at 6 to 8 kilometres per second. After an earthquake, most nearby places will experience the seismic waves in less than 20 seconds. In some places damage may be caused by very large distant earthquakes, allowing time for a warning. In Mexico City, waves from large earthquakes along the south coast of Mexico can be detected in time to give about one minute's warning in the city. In Japan, very fast trains receive a warning 10 to 20 seconds before seismic waves arrive from large earthquakes off the east coast, allowing trains to slow down. Power stations can receive a warning within a couple of seconds before strong motion from a nearby large earthquake, allowing disconnection of turbines and generators, and reduction of damage.

There are natural warnings that simply require observation and knowledge. A natural warning for a tsunami that was generated nearby is given by feeling an earthquake (meaning that it is relatively close) that lasts more than ten seconds (meaning that it is relatively large), so if near a shoreline one should immediately head for higher ground. A tsunami may arrive within minutes to tens of minutes.

Alarm

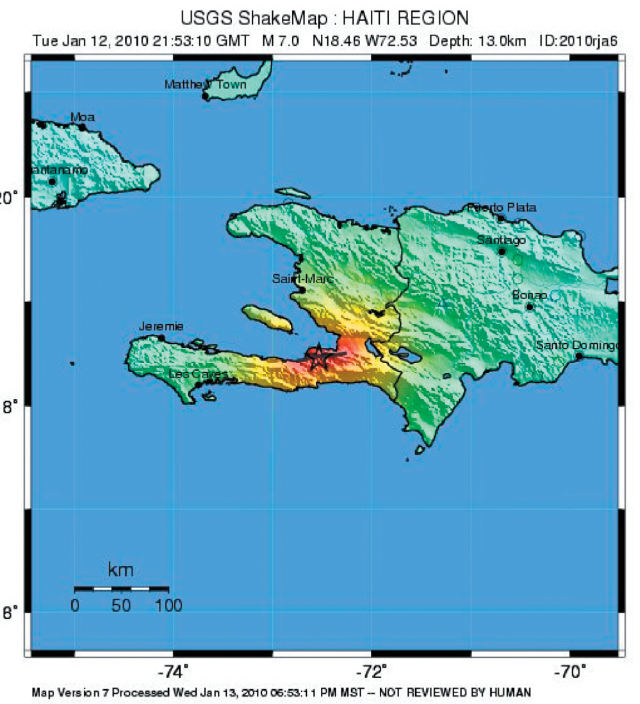
An alarm occurs after the event has initiated, and is provided to alert people of the event (e.g. fire alarms), and to people who will assist those who have been affected (something has happened, its effects have been felt, and here is some information that may assist in your response).

The information provided with an alarm can include expected effects of the event, based on scenario studies undertaken as part of the establishment of the alarm system. In the case of an earthquake, provision of the earthquake location (longitude, latitude and depth), magnitude and focal mechanism can be of little value to non-specialists. The alarm should also include estimated effects of the earthquake, based on studies of past earthquakes in both the locality and elsewhere.

The water supply industries in Victoria and New South Wales have been receiving earthquake alarms for almost 20 years. These alarms include information about the earthquake itself, and a list of likely effects of the earthquake in order of importance, based on the location and size of the earthquake relative to their dams, pipelines and other facilities. In most cases the earthquake alarm forms part of the organisation disaster response plans, and includes a list of tasks to be undertaken. The earthquake alarm is provided within 20 to 30 minutes of the earthquake.

In Australia, where small earthquakes can generate much media interest, most earthquake alarms confirm that an earthquake has occurred, but was too small to cause problems.

Internationally, the United States Geological Survey publishes the USGS ShakeMap after all large earthquakes and moderate magnitude shallow earthquakes, providing estimates of the ground shaking that will result from the earthquake. In the case of the Haiti earthquake, this map was published on the USGS website nine hours after the event (Figure 2), and the intensity



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 2. Effects of Haiti earthquake as estimated 9 hours after it occurred.

associated with the highly populated area indicated a disaster of catastrophic proportions. A preliminary study produced before details of the fault rupture were available would have given a similar indication within an hour of the event.

Anticipation of future earthquakes

Earthquakes depend on the stress and strength of rocks in the seismogenic zone, to depths of about 20 kilometres in continental regions, and to several hundred kilometres at those plate boundaries where one plate subducts under the other. Large earthquakes rarely initiate at shallow depths, although they may rupture through weaker rocks in the top couple of kilometres. We cannot directly measure either the stress or the strength of faults at the depths of earthquakes' occurrence.

The recurrence of large earthquakes appears to be fairly random, but it follows a cyclic process, as follows:

- **Quiescence** – long period without much activity, with stress below that required to rupture the fault, but building up through deformation resulting from plate motion.
- **Precursory events** – for some, but not all, larger earthquakes (usually greater than Mw 6.5 in continental regions, and less obviously but certainly larger than this at active plate boundaries), repeated small clusters occur weeks to years before the main event, perhaps associated with initiation of rupture process.
- **Foreshocks** – minutes to days before main event, possibly 'unlocking' the mainshock.
- **Mainshock** – largest event in the sequence.
- **Aftershocks** – many events in following days to months, rapidly decaying in numbers, possibly associated with the mainshock rupture. Larger earthquakes have many more aftershocks than smaller earthquakes, and shallow earthquakes usually have more aftershocks than deep earthquakes.
- **Adjustment** – following larger earthquakes only (greater than Mw 6.5 in continental regions, less obviously but certainly much larger at active plate boundaries) slowly reducing activity over many months to hundreds of years, perhaps associated with regional stress changes.
- **Quiescence** – another long period without much activity, with stress building up.

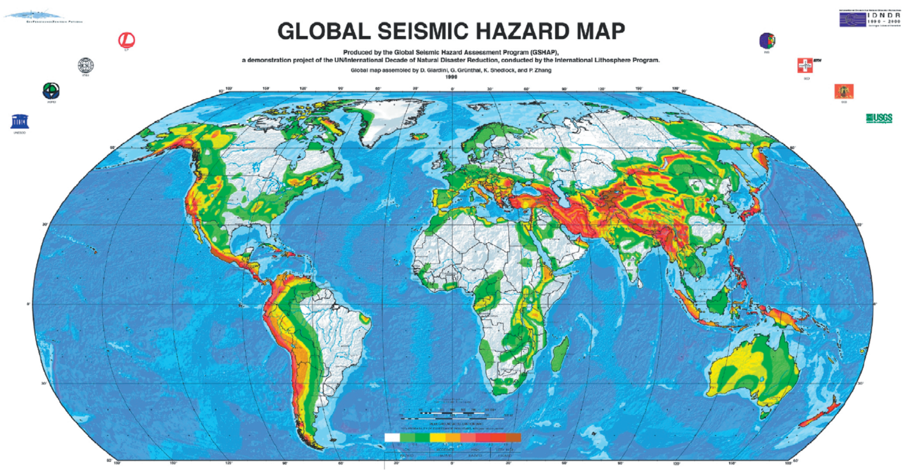


Figure 3. Global Seismic Hazard Assessment Project, GSHAP 1999.

The process is cyclic because it follows a sequence of stress changes, but is not periodic (large earthquakes do not occur at equal time intervals) because stress is being affected by neighbouring activity, and possibly even by great earthquakes on nearby plate boundaries.

The difference between the cyclic behaviour in continental regions and plate boundaries is probably due to the high stress in stable regions (where faults are strong), and low stress in active regions (where faults are weak because they are often failing).

Even disregarding aftershocks, there is no doubt that the level of seismicity for small earthquakes is higher in regions that have recently experienced many or large earthquakes.

However, large earthquakes often occur in regions that have been in the quiescent stage of the earthquake cycle, and often occur in regions with a recent history of little or no known activity. Recent examples include the Wenchuan earthquake of magnitude 8.0 in Sichuan, China on 12 May 2008, and the Haiti earthquake of magnitude 7.0 on 12 January 2010.

An area with low seismicity over the recent past (say 50 to a few hundred years) can mean that the region does not have many earthquakes, or it may mean that the region is about to have a larger earthquake. These might be distinguished using the geological history of the region. If there has been little geological deformation since the current stress field was established (up to tens of millions of years in Australia, typically mid-Miocene), and especially over the past million years (Quaternary), then the region probably will be stable. The more geological deformation that has occurred over these periods, the more likely it is that a quiescent period will end with a larger magnitude earthquake. In some cases, but not all, it may be preceded by precursory events.

At present, future earthquakes can be considered in four ways: hazard estimates, alerts, forecasts and predictions.

Hazard estimates

A hazard estimate gives the ground motion that is estimated to be exceeded on average in a given return period. It is computed considering the probabilities of all earthquakes that may occur in the region, defined by the rate of earthquake activity, relative number of small and large earthquakes, and the maximum credible earthquake magnitude for the tectonic setting. It also uses the attenuation of ground motion with distance from each earthquake in this region.

The Global Seismic Hazard Assessment Project produced a world map (Figure 3) giving the peak ground acceleration expected with a probability of 10% in 50 years (equivalent to a 475-year return period). The hazard was plotted in nine zones, from low to high with logarithmic increments

The Australian earthquake hazard map used in the loading code AS1170.4 is shown in Figure 1 of McCue, this volume.

The earthquake recurrence distribution was based mainly on historical seismicity, in most places using relatively little data from before 1960. As a result, this underestimated the hazard in quiescent regions, resulting in Port-au-Prince, Haiti being included in the fourth lowest zone (yellow), along with the larger Australian cities. If the methodology had considered the tectonic setting and the geological deformation, then Haiti would have been in a higher hazard zone. Considering the poverty in Haiti, it is unlikely that consideration of a more realistic hazard rating would have led to improved building standards before the 12 January 2010 earthquake, but more preparation could have occurred.

Hazard studies are now often based on instrumental seismology (in most cases since about 1960), historical seismicity (since 1800 to 1900 for different parts of Australia), and geological evidence, especially local deformation over the past million to ten million years.

Hazard studies are used to produce regional hazard maps for earthquake building codes, and for site specific design of major structures such as dams, large mines, petroleum and gas facilities, power stations, etc.

Alert

An alert may be given when there is an enhanced probability of future activity for some reason. For example, the Western Strzelecki Range region in Victoria near Korumburra is a region with significant deformation over the past few million years, and is bounded by faults with hundreds of metres displacement and lengths of tens of kilometres. The area experienced relatively little local earthquake activity over the 150 years to the beginning of 2009. A local earthquake with magnitude 3.7 was felt in January 2009, followed by two events of magnitude 4.6 in March that were felt to Melbourne and beyond. Activity has continued to the end of 2009, with over 200 events in all, although with none exceeding magnitude 3.0 since July 2009. The duration of this sequence is much longer than the normal aftershock duration for a magnitude 4.6 event. They are at depths from 6 to 8 kilometres beneath the surface, so are unlike the shallow swarms that occur every couple of years in Australia, and they are very close to the expected location of the larger bounding faults for the Strzelecki Ranges.

The most likely outcome is that the events will slowly decay to normal rates of activity, but in the meantime it would be prudent to assume a significantly enhanced probability of another moderate or larger event during the next few years.

Forecast

A forecast of a future earthquake includes an estimated probability of occurrence, usually exceeding 10%. A forecast goes well beyond the hazard estimate, in that it considers a particular earthquake. The origin time must be estimated to within a specified interval, usually not longer than years or tens of years, the location defined to a relatively small region, usually of dimension from kilometres to tens of kilometres, and the forecast magnitude range covers less than 2.0 magnitude units.

An earthquake forecast is comparable with the estimated rain in a weather forecast, where the probability for 5 to 10 mm of rain on a particular day may be 20%. To evaluate the value of the rain forecast requires consideration of the results of many forecasts. At present, several earthquake forecast theories are being tested to check whether these give results better than a random guess, with some limited progress evident.

Forecasts may be possible using patterns of seismicity, but, unless there is a major breakthrough, their extended location, time and magnitude ranges mean that forecasts are unlikely to be of significant immediate practical value.

Prediction

A prediction of a future earthquake assumes that the earthquake will occur in the specified ranges defining location, time and magnitude as used for a forecast. If it does the prediction is successful, and if not the prediction has failed. The specified ranges must be small and/or short enough to give a negligible probability of occurrence by random chance.

The vast majority of predictions published before the event fail, and the vast majority of predictions that succeed are published after the event. Some of these may have some value, as they show that the method would have predicted the event.

Most seismologists believe that it is unlikely that earthquake prediction will ever be reliable, or will ever be able to give an accuracy within narrow location, time and magnitude ranges.

Earthquake predictions most likely to be successful will involve monitoring of local phenomena (ground water behaviour, radon gas emission, electrical properties, etc). Such predictions are likely to be just before the earthquake occurs, and they will require monitoring with appropriate equipment, at the right place, at the right time.

Conclusion

The most significant earthquake risk mitigation is by improved building standards. The risk criterion used for the building standard in regions of low seismicity, like Australia, may be increased to perhaps 2500 years, providing more security than the current criterion.

The most important factor in response to earthquakes is the level of preparation. This includes knowledge and understanding of earthquakes by the public and emergency responders, plus the availability of supplies, transport and communications. Decisions and response should be within hours, not days.

Because of the high speed of seismic waves, there is rarely time available for an earthquake warning, However, earthquake alarm systems can provide useful information about estimated effects very soon after the earthquake, especially if alarms are related to the disaster response plan.

Anticipation of future earthquakes involves significant uncertainties. Earthquake hazard studies provide a model for building codes or design of major structures according to an adopted risk criterion, and require an estimate of earthquake recurrence as it varies with magnitude and space.

Anticipation of particular earthquakes can be classified into earthquake alerts, earthquake forecasts and earthquake predictions. Much work is required before these are reliable, and it is likely that earthquake predictions within narrow location, origin time, and magnitude ranges will never be possible.

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