

PREVIEW MODE: ON EARTHQUAKE RISK IN STABLE, INTRAPLATE REGIONS: THE CASE OF PERTH, AUSTRALIA

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EDITOR'S NOTE: There is often a tendency to discount earthquake risk in regions where earthquakes occur infrequently. It is a tendency that carries its own risk. For some regions, the historical record is too short to provide a realistic view of long-term risk. And several factors other than frequency contribute to the potential for large losses. In this article, AIR Senior Scientist Dr. Khosrow Shabestari discusses some of those factors in the context of a comparison between earthquake risk in Perth, Australia, and Wellington, New Zealand.

By Dr. Khosrow Shabestari

More than 90% of earthquakes occur along the boundaries of tectonic plates. It is here that massive and constantly moving pieces of the Earth's crust interact, sometimes sliding past each other with a horizontal relative motion to form what is known as a transform boundary, sometimes converging to form subduction zones or mountain ranges, and sometimes diverging to form rift valleys and mid-ocean ridges. Last month's magnitude 7.0 earthquake that killed an estimated 200,000 and levelled the Haitian capital of Port-au-Prince occurred at the boundary between the Caribbean and North American plates.

But earthquakes occur, too, in the interior of tectonic plates. Here, the sources of seismicity are not as well understood. Scientists believe that these intraplate regions are characterized by traces of ancient geological deformations, or zones of weakness, that resulted from the collision and rifting of tectonic plates over hundreds of millions of years. These zones of weakness in otherwise stable regions characterized by low seismicity can be reactivated by present-day stresses.

The temptation is to discount, or even dismiss earthquake risk in such regions. To do so, however, can be misguided—and the cost of doing so can be quite high. Earthquake risk is not defined by seismicity alone; instead, risk is a combination of seismicity (the frequency and intensity of earthquakes), the rate at which seismic waves diminish as they travel through geological materials from source to site, the surface soils at the site, which may amplify or deamplify incoming ground motion, and the vulnerability of the structures subjected to that ground motion. To illustrate the idea that earthquake risk in a region characterized by relatively low levels of seismicity can be comparable to earthquake risk in a seismically active region, this article examines the drivers of risk in Perth, Australia, which is—perhaps surprisingly—characterized by a level of risk that is roughly on par with that of Wellington, New Zealand.

HISTORICAL SEISMICITY IN THE PERTH REGION

If 90% of earthquakes occur along plate boundaries, the vast majority of the world's largest earthquakes occur along the Circum-Pacific Belt, also known as the Ring of Fire. New

Zealand lies here, and New Zealand's seismicity is vividly illustrated in Figure 1. Australia, on the other hand, is a stable continent situated within the center of the Indo-Australian Plate. Nevertheless, Australia has experienced several moderate to large earthquakes in the relatively recent past.

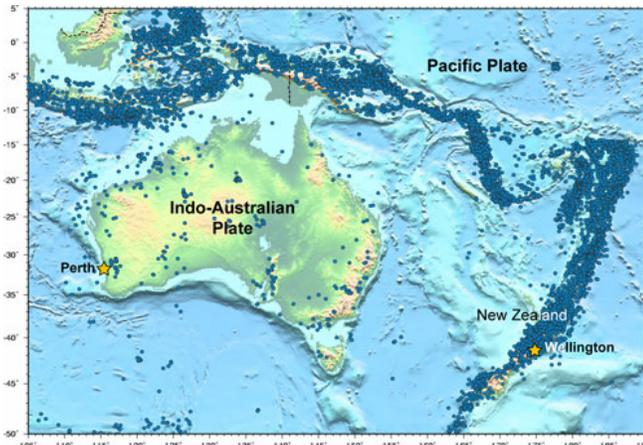


Figure 1. Tectonic setting of Australia and New Zealand. (Source: AIR)

Australia's historical record, however, is quite short. Most of the recorded events have occurred in the last 150 years and have been located in areas of low population density. The largest earthquake on record—a moment magnitude (Mw) 7.3 event—occurred in Meeberrie, Western Australia in 1941.

The Perth area has exhibited high levels of seismicity compared to other regions of Australia. A number of damaging events, including the 1968 Mw6.9 Meckering earthquake and the 1979 Mw6.2 Cadoux earthquake, occurred in this region (Figure 3). These events generated an awareness of the need to consider earthquake hazard in metropolitan Perth and, as a result, Geoscience Australia (GA) has recently adopted a probabilistic approach that addresses uncertainty on the distribution of future earthquakes in and around Perth¹.

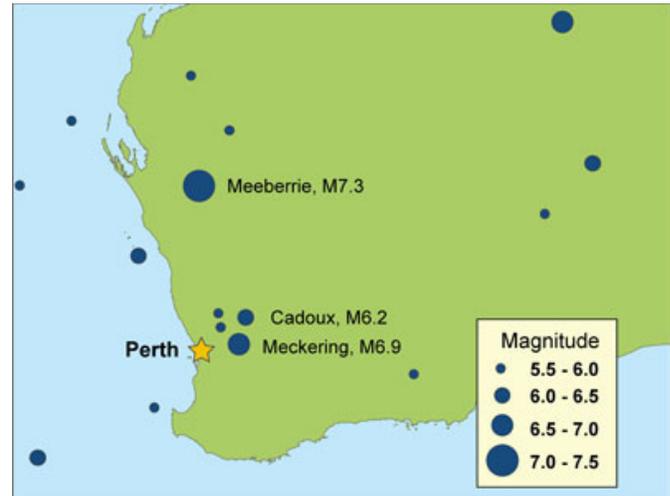


Figure 2. Historical seismicity in Western Australia, Mw5.5 and higher. (Source: AIR)

AIR SEISMICITY MODEL FOR AUSTRALIA

AIR Worldwide (AIR) first released a probabilistic earthquake model for Australia in 1998 and the model has been updated several times since to include the results of published scientific research. In the AIR model—and in line with common practice—the probability that an earthquake will strike in a particular location is estimated based on the premise that historical seismic activity can be used to calculate the frequency (and magnitude) of future events. However, given the short historical record and the significant uncertainty surrounding the locations of faults in Australia, reliance on the historical record alone could lead to a potentially inaccurate view of the long-term seismicity in the region.

In accordance with Geoscience Australia, the AIR model implements seismic zones. These are based on the work of Gaull et al. (1990)², who defined 32 zones, some of which were defined purely by a visual inspection of the distribution of historical seismicity, while others are associated with geophysicists' understanding of ancient fault zones, geological basins, or zones of high topographic gradient, such as continental margin.

AIR modified and extended the work of Gaull, however, by introducing uncertainty in the boundaries of the source zones—in effect, by “blurring” the boundaries using a spatial Gaussian distribution. In addition, AIR implemented smoothed background seismicity—with eastern and western Australia being modeled separately on the basis

of geological criteria—in areas outside of the 32 source zones to capture the potential for earthquakes to occur where there has been little or no recorded historical seismic activity.

Indeed there is no historical record of a damaging earthquake having occurred in Perth. However the metropolitan area is located near the most active seismic zone in Australia. Therefore, for long-term risk assessment in the tectonically stable region applying back ground seismicity concept is essential to get more realistic picture of regional seismic hazard.

GROUND MOTION RELATIONS

Ground shaking intensity at any given location depends in part on the rate at which the amplitude of seismic waves attenuates, or decreases, as the waves propagate outward from the initial source of the rupture. This decrease is caused by the absorption and scattering of energy as the waves travel through the earth.

The tectonic and geological characteristics of a region can have a dramatic influence on attenuation. Differences in the elastic properties of the surrounding rock, for example, can result in earthquakes of the same magnitude affecting geographical areas of vastly different size. The tectonic stresses and relentless grinding that occurs along plate boundaries such as the one on which Wellington, New Zealand, lies can result in significant fracturing of the rock. This fracturing results in a relative rapid scattering of seismic energy. For an earthquake of the same magnitude, the denser and generally older rock of intraplate regions such as Australia propagates seismic energy over a much larger area. The implication is that an earthquake can occur at some distance from Perth, but still cause damaging ground motion in the metropolitan area.

Catastrophe models employ attenuation relationships, or ground motion prediction equations (GMPEs), that mathematically relate ground shaking intensity to earthquake magnitude and distance from the earthquake rupture. Based on the tectonic characteristics of Australia and their similarity to those of the intraplate regions of Central and Eastern North America, GMPEs used for the central and eastern United States are generally adopted for Australia. Geoscience Australia, in its most recent national seismic hazard maps does so, as does the AIR Earthquake Model for Australia.

The effect of the GMPEs for Australia is illustrated in Figure 3, which shows the percentage of simulated earthquakes in AIR earthquake model catalogs for the Wellington and Perth regions with ground motions that exceed certain levels of PGA, 0.3s Sa, and 1.0s Sa.³ For example, about 1.3% of the simulated events within 100km of Wellington cause PGA in Wellington that exceeds 0.2g, whereas roughly 8% of events within 100 km of Perth cause ground motions there that exceed 0.2g. While this does not entirely offset the higher seismicity that Wellington experiences in terms of earthquake frequency (a factor of about 10), it certainly compensates to some degree—putting Perth at greater risk than seismicity alone would suggest.

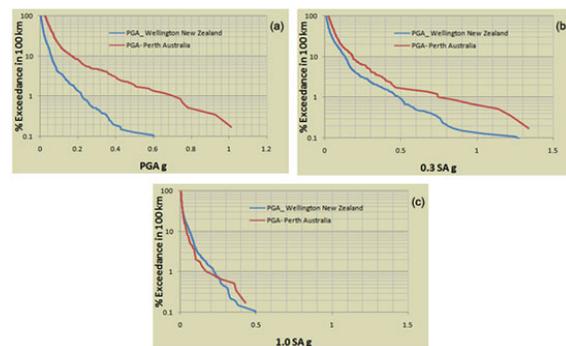


Figure 3. Percentage of simulated earthquakes in the Wellington and Perth areas with ground motions exceeding certain levels for a) PGA, b) 0.3s SA, and c) 1.0s SA. (Source: AIR)

LOCAL SOIL CONDITIONS

GMPEs provide estimates of shaking intensity that reflect the characteristics of the geological materials through which seismic waves travel. These must then be modified to reflect local site conditions and, in particular, the characteristics of the soils beneath the exposed structures. Certain types of soil can amplify shaking intensity; others may be susceptible to liquefaction.

Perth is located above 30 to 80 meters of soft sediments—Quaternary sands, mud and limestone—that make up the Perth Basin, beneath which is Proterozoic basement rock. The ground motion on such basins can be amplified above and beyond what would be expected using the near-surface soil stiffness parameter only, and this is particularly true for weak ground motions from relatively distant events. This so-called basin effect was perhaps most vividly seen in the 1985 Michoacan, Mexico, earthquake which, despite occurring some 300 kilometers distant from Mexico City, caused catastrophic damage there.

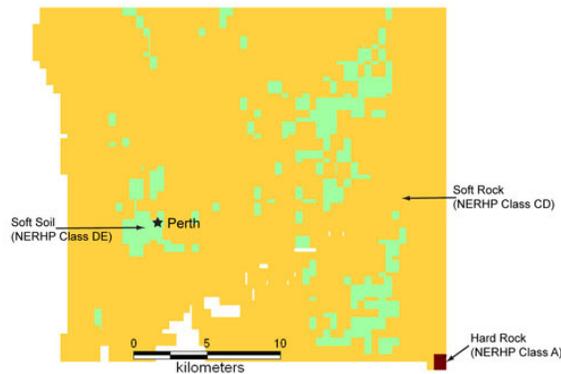


Figure 4. Local soil condition map in Perth region used in AIR Australia earthquake model. Perth area which is located in Perth Basin has a soft soil condition. (Source: AIR)

BUILDING VULNERABILITY

Due to its tectonic setting—lying as it does on the boundary between the Indo-Australian and Pacific plates—there is no question that New Zealand experiences significantly higher seismicity than does the stable intraplate region that comprises Australia. As has been discussed thus far, however, other factors act to at least partially level the playing field in terms of earthquake *risk*. A final factor is the relative vulnerability of the building stock in Perth and New Zealand.

For the very reason that New Zealand is more seismically active, building code there is much more stringent than in Australia. Indeed, the current building code in New Zealand is comparable to current code in the U.S. state of California, and both fall in the high-code class according to HAZUS4 criteria. Australia building code, on the other hand, belongs to a low-code class and is roughly equivalent to the California building code dating back to the 1950s. Thus from a vulnerability standpoint, Australia's building stock is generally less resistant to ground shaking than New Zealand's.

Exacerbating matters, the building inventory in Perth is dominated by unreinforced masonry construction, which is among the most vulnerable to ground shaking. The most recent Australian standard for masonry construction (2001) includes requirements to take seismic loads into consideration for new construction, but there is considerable uncertainty with respect to the enforcement of these standards. Seismic retrofit of existing buildings has been recommended, but only for critical facilities, such as hospitals, and fire and police stations.

CONCLUSION

As noted in the introduction to this article, earthquake risk is not defined by seismicity alone. Ultimately, earthquake risk comprises all of the factors that determine financial loss. Earthquake ground motion is modified by the tectonic and geological (crustal) materials through which seismic waves travel, which vary from region to region, and by site-specific soil conditions, which may amplify seismic waves. Finally, the vulnerability of the built environment exposed to ground shaking figures significantly in any estimation of earthquake risk.

As we've seen here, even a region of low seismicity such as that of Perth Australia can be at significant seismic risk—similar, even, to a seismically active region such as Wellington, New Zealand. An understanding of *all* of the factors that comprise earthquake risk is essential for the development of effective risk management strategies.

1 JONES, TREVOR, ET AL., NATURAL HAZARD RISK IN PERTH, WESTERN AUSTRALIA, GEOSCIENCE AUSTRALIA, 2005.

2 GAULL, B., M. MICHAEL-LEIBA AND J. RYNN, "PROBABILISTIC EARTHQUAKE RISK MAPS OF AUSTRALIA", AUSTRALIAN JOURNAL OF EARTH SCIENCES, 37, PP 169-187, 1990.

3 VERY GENERALLY, LOW- AND MID-RISE BUILDINGS ARE MORE SUSCEPTIBLE TO SPECTRAL ACCELERATION (SA) 0.3S, WHILE HIGH-RISE BUILDINGS ARE MORE SUSCEPTIBLE TO SA 1.0S. HOWEVER, IT SHOULD BE UNDERSTOOD THAT THE ACTUAL RESPONSE OF A BUILDING TO EARTHQUAKE GROUND MOTION IS MORE COMPLEX THAN A SINGLE GROUND MOTION PARAMETER CAN FULLY DESCRIBE.

4 A GIS-BASED NATURAL-HAZARD LOSS-ESTIMATION SOFTWARE PACKAGE DEVELOPED BY THE U.S. FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA).

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