Earthquake Hazard In Papua New Guinea: Problems And The Way Forward

Lawrence Anton[1] and Gary Gibson[2]

[1]Port Moresby Geophysical Observatory, Department of Mineral Policy and Geohazard Management, Port Moresby, Papua New Guinea. Currently with School of Geosciences, Monash University, undertaking Master of Science Degree.

[2]Monash University, Melbourne, and Environmental Systems and Services, Seismology Research Centre, Melbourne.

Summary

Earthquake hazard assessments have been undertaken in PNG since the 1960s but most early studies were based on limited data. Unfortunately, very little earthquake hazard work has been done within the country over the past ten years, a period that has seen significant development in earthquake hazard methodology. Databases with improved earthquake catalogues are now available, the geology and tectonics of the region are better understood, improved attenuation functions for motion from the deep earthquakes in subduction zones have been developed in other countries and may be applied in PNG, and hazard computation methods have improved.

However, over recent years the local seismograph network coverage in PNG has deteriorated, and now only moderate and larger magnitude earthquakes are being located, mainly using data from the global seismograph network. Without a local seismograph network, the hypocentral locations of most events have relatively large uncertainties, and the magnitudes of smaller events are poorly determined. Replacement of the seismograph network with modern equipment will lead to a significant increase in the rate at which earthquakes are being located, and in the precision of locations and magnitudes.

The earthquake hazard estimates and zoning maps for PNG developed in the 1970s are now due for review and replacement.

This project has been funded by the Australian Government to develop a new seismotectonic model using information from geology, geophysics, geodesy and seismology. It will include area earthquake source zones and active faults that will have their seismicity quantified so as to be consistent with all available data. Appropriate ground motion attenuation functions will be selected, and verified as being consistent with the limited PNG strong motion data that are currently available. Using these, initial computations of earthquake hazard will be undertaken for representative locations within the next year, and it is anticipated that these will lead to revised hazard maps in the following two years.

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Lawrence Anton
School of Geosciences, Monash University, Wellington Road, Clayton, Victoria 3800, Australia, Email: lawrence.anton@sci.monash.edu.au; Tel: 03 9905 4973; Fax: 03 9905 4903

Gary Gibson
Monash University, Melbourne, and Environmental Systems and Services,
Seismology Research Centre, Melbourne.

Introduction

The project currently being undertaken aims to revise earthquake hazard estimates for Papua New Guinea. It was funded by the Australian Government, and will consider all aspects of earthquake risk mitigation, but will concentrate on those aspects where existing data are available to allow development of a revised seismotectonic model, and revised ground motion recurrence estimates. This will be used to produce hazard estimates at representative locations over the next year, and will be followed by further revisions and development of a national hazard map in the following two years.

Earthquake catalogues for Papua New Guinea (PNG) include a few very large events before 1900, and most of the larger earthquakes that have occurred since 1900. Improved global seismograph coverage installed following the International Geophysical Year in 1957-58 has led to many smaller PNG earthquakes being located since about 1964. Local seismograph networks within PNG in the 1970s and 1980s reduced uncertainties in hypocentres, so earthquake distribution patterns and tectonic interpretations have improved. Sourced from numerous agencies and individuals, a revised earthquake catalogue is now in the Port Moresby Geophysical Observatory (PMGO) database.

The most useful and reliable earthquake hazard studies are based on local earthquake data accumulated over a long period of monitoring. High-resolution earthquake locations from a dense local seismograph network will allow delineation of active source zones and faults. Recording of strong motion from moderate and larger nearby earthquakes will provide constraint for attenuation estimates. In a region vulnerable to tsunamis, landslides and flooding generated from or induced by earthquake occurrences, the developing nation needs the services of a better seismic network for purposes of risk mitigation.

Very few measurements have been made to quantify the attenuation of strong motion with distance in PNG, an essential component of hazard studies in an active area where attenuation is relatively high. Without this, the magnitude estimates of small to moderate earthquakes are highly uncertain, and thus of limited use in hazard studies.

However, local seismograph networks in PNG have not been sufficiently maintained, and the local earthquake coverage has deteriorated over the past ten years. Mostly, this has been due to the lack of funding, as there has been no firm commitment in this regard from either the government or corporate sectors. Replacement of the seismograph network using modern equipment for both sensitive and strong motion strong recordings of local earthquakes in the PNG region is urgently needed.

Despite these limitations, at this stage adequate data are available to develop preliminary replacements for the current earthquake hazard maps that were originally produced in 1971. Available data includes seismicity from the global seismograph network, and geological and tectonic data from recent mapping, mineral and petroleum exploration, and geophysical surveys. Work being undertaken in similar tectonic environments elsewhere can be applied in PNG, such as the use of seismic wave attenuation functions derived using data from other comparable subduction zone regions.

Past Hazard Studies

The first attempt to quantify earthquake hazard in Papua New Guinea was by Brooks (1965), who used earthquakes from 1906 to 1959 to estimate recurrence intervals of larger earthquakes, and represented hazard with intensity maps for recurrence intervals for 25, 50 and 100 years.

Studies were later undertaken to support building codes for earthquake design of bridges (Beca *et al*, 1976), and for buildings (Jury *et al*, 1982). These included peak ground acceleration maps for a recurrence interval of 20 years, and a seismic zonation map based on these estimates. The hazard and vulnerability aspects of both are now in need of revision.

Denham and Smith (1993) gave a review of earthquake risk in the Southwest Pacific region, including PNG, in the Technical Planning Volume for the Global Seismic Hazard Assessment Project (GSHAP) undertaken for the United Nations International Decade of Natural Disaster Reduction. McCue (1999) used available ground motion recurrence calculations to contour the PNG map incorporated into the GSHAP map of global hazard.

Using a yearly extreme magnitude method and the magnitude 7 earthquake record since 1900, Ripper and Letz (1993) determined return periods and probabilities of occurrence of these earthquakes in normalized 10,000 km^2 areas. The return periods for magnitude 7.0 earthquakes for Bougainville Island, New Britain, Huon, West Bismarck, North Sepik and Ramu seismic zones are only 37, 60, 81, 88, 125 and 125 years respectively.

Since the 1970s, other seismic hazard analyses have been undertaken for various sites in PNG, particularly dams, mines and petroleum facilities. These have been mainly based on a limited and imprecise earthquake catalogue, without detailed consideration of geology or geophysics (especially gravity and magnetics), geodesy or palaeoseismology.

Regional tectonics

It is apparent from emerging earthquake patterns, especially with earthquake data since 1964, that much of the PNG landmasses have a very high level of earthquake activity. Exceptions include the southern part of Papuan Peninsula region (including the National Capital District and city of Port Moresby), the central PNG Highlands, and the southwestern part of PNG mainland (Western Province). The region which includes the southern part of the Papuan Peninsula and Western Province has been identified as part of the stable Australian craton. The central PNG Highlands is probably a tectonic block not recognized previously (Wallace et al., 2005). Pubellier and Ego (2004) recognized the Bird's Head region of Papua Province, Indonesia, as a separate tectonic block which moved away left-laterally from the main collision axis.

In the east, within the collision zone of the major Pacific and India-Australia Plates, are the Solomon, South and North Bismarck, and Caroline Plates (Ripper and Letz, 1993). To the east of the collision zone, bordering and dominating the Pacific Plate front, is the massive oceanic plateau – the Ontong Java Plateau (OJP). The largest on the planet, the OJP was too thick and buoyant to subduct at the Bougainville-Solomon Trench when it arrived there 25-20 million years ago. It subsequently caused a reversal of the SW-directed subduction to NE-directed subduction 6 million years ago (Yan and Kroenke, 1993; Petterson et al., 1999; Mann and Taira, 2004). This feature is now the source of most seismicity in the region coupled with the subduction of the Solomon Plate at both this front and the South Bismarck Plate front. The subduction is in turn responsible for the opening of the Woodlark and Manus Basins. The reality may be that the Solomon Plate is being annihilated, and taken out of existence in the region.

PNG region seismicity

Earthquake distribution patterns in the PNG region are gradually resolving. Most earthquakes occur along tectonic plate boundaries, and along zones of plate deformation. Further, earthquakes associated with volcanic activity occur well away from the plate margins along volcanic arcs.

What is now reasonably understood from the seismicity of the PNG region is a result of detailed study by many workers over the past 40 years. The distribution of seismicity in the region is shown in Figure 1. Activity is greatest in the area covering the northern Solomon Sea, western Bougainville, southern New Ireland and eastern New Britain, while the area of lowest activity is in south and southwest PNG (Ripper and Letz, 1993).

The comprehensive International Seismological Centre (ISC) earthquake catalogue now gives the best available data for analysis of earthquake hazard, and is being used in this project to delineate earthquake source zones, and to quantify the activity on each.

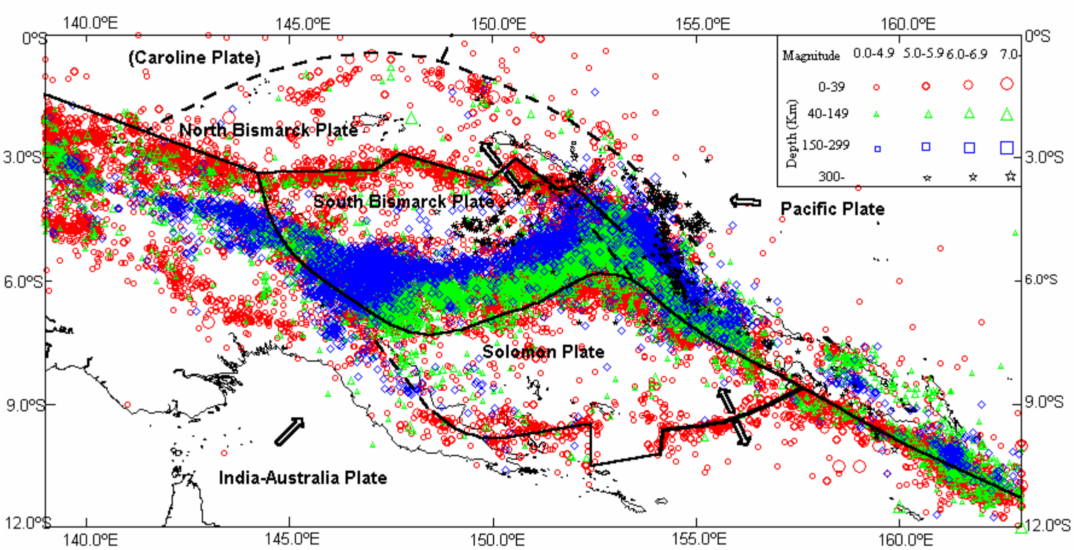

Figure 1. PNG seismicity superimposed on the tectonic plate boundaries (from Ripper and Letz, 1993). Red circles denote depth range 0-39 km, green triangles denote range 40-99 km, blue diamonds denote range 100-299 km and black stars denote depths greater than 300 km.

Seismic Instrumentation in PNG

Locations of past and present seismographs and strong motion accelerographs that have been operated by the Port Moresby Geophysical Observatory are shown in Figure 2.

The Rabaul Volcano Observatory (RVO) has operated a seismograph network within the Rabaul Harbour for many years, and other instruments at volcano locations on New Britain, Bougainville, and near northeastern coast and eastern coast of PNG mainland. The Seismology Research Centre installed two other networks during the 1980s, on Bougainville (five stations) and at Yonki (4 stations), for Bougainville Copper Limited and the Electricity Commission of PNG respectively.

The difficulties faced in keeping the PNG seismograph network operational include the hot and wet climate, very high communication and transport costs, lack of spare parts, and the need for technical training. The national network has deteriorated over the past ten years, and currently only the Port Moresby and Rabaul stations are operating. The nearest seismograph to a PNG earthquake is often at a distance of many hundreds to more than a thousand kilometres. This results in large earthquake location errors of tens of kilometres. Because of the sparse local network, only events larger than about magnitude 4 to 4.5 are located using the global seismograph network. Because of the complex lithosphere, these have limited accuracy for both magnitude and hypocenter determinations.

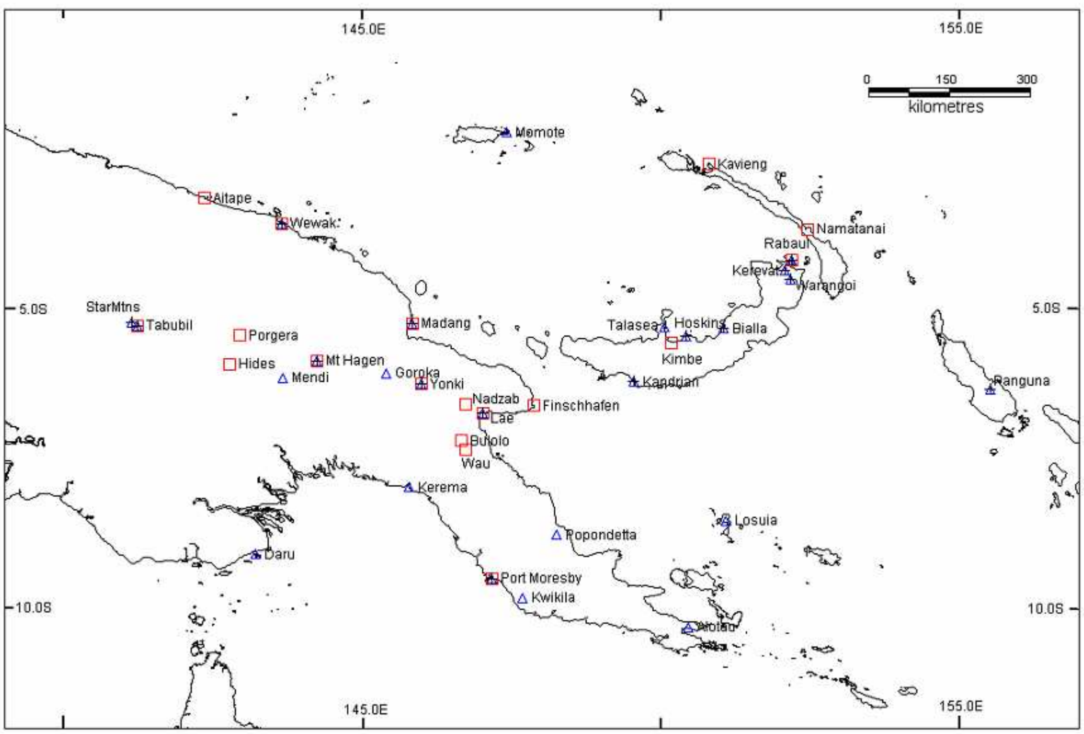

Figure 2. PMGO seismograph locations. Squares show locations of seismographs operated within the past ten years. The only seismographs currently operating are at Port Moresby and Rabaul. Crosses and triangles are locations of accelerographs and seismographs respectively, as operated by PMGO in the 1970s and 1980s. A few accelerographs were installed in the 1990s, but none of these are currently operating.

The few analogue accelerographs operated in the 1970s and 1980s have provided some strong motion records for attenuation studies.

Attenuation in PNG

Earthquake shaking usually reduces with distance as a result of geometric spreading, and absorption of energy within rocks (especially young, soft and hot rocks as found in PNG), and scattering by interfaces between rock types. Surface motion at local sites is amplified or attenuated because of the complex geology involved, making attenuation studies very difficult to implement. Within the PNG region, numerous tectonic blocks co-exist with zones of lithospheric slab contortions and detachments. There are zones of crustal extensions and zones of folds-and-thrusts, which accommodate compression due to active convergence. Also, valleys filled with deep sediment will readily amplify long period seismic waves, while attenuating motion of short period waves. Records from the few accelerographs operated in the past include accelerations on sediments and hilly topography that are abnormally high, up to ten times that on nearby firm foundations.

As a result, detailed local attenuation studies will require a dense seismic station network, and in particular strong motion recordings from epicentral areas of local events are needed to determine local attenuation functions. In this complex region, it is envisaged that no single attenuation relationship will apply over the whole region (Ripper, 1992).

Ideally spectral attenuation relationships for the PNG region should be derived from analysis of local seismograms and strong motion accelerograms. However, at this stage attenuation relationships that have been derived using data from regions with a similar tectonic environment outside of PNG will be selected. These can be tested against the available PNG strong motion data, which incudes a collection of accelerograms recorded on medium or soft foundation, some of which have been analysed by the then Bureau of Mineral Resources, Geology and Geophysics (now Geoscience Australia) and others have been analysed by PMGO (Ripper, 1992).

The PNG building construction seismic zoning map

The current seismic zoning for building construction in PNG was introduced in 1971 (PNG Statutory Instrument No. 44 of 1971), based on the occurrences of earthquake intensity 8. The seismic zoning was later revised when the PNG National Standards Council and Department of Works, in consultation with various PNG authorities, commissioned engineering consultants Beca, Carter, Hollings and Ferner Ltd to develop a seismic zoning map. The development of the seismic zoning map was reported by Jury, et al. (1982) and PNG National Standards Council (1983). This map is shown in Figure 3.

It has been recognized for some time that this map of seismic zones is in need of revision. Adequate local attenuation data was not available when the seismic zoning map was developed, which led to use of data from Indonesia and New Zealand in the development of the map. The zoning was criticized, for example by McCue (1984), because it does not closely match the seismotectonic framework of PNG.

Comparing Figures 1 and 3, the well recognized plate boundaries and seismic zones of the Bismarck and Solomon Seas are not reflected in the seismic zoning map. The seismic zone of the Papuan Fold Belt, which coincides with a broad zone of Pliocene/Quaternary faulting and folding caused by collision of the South Bismarck and India-Australia Plates, is also not properly reflected. This seismic zone should appear as a separate feature, as it is separated by a large distance (approximately 300km) from the seismically active northern coast of PNG mainland. A third concern is that Seismic Zones 3 and 4 of mainland PNG should be in better agreement with the seismicity and geology of the western part of the Solomon Plate.

A revision of the PNG seismic zoning is now possible using the PMGO earthquake database, with additional input from geology, geophysics and geodesy.

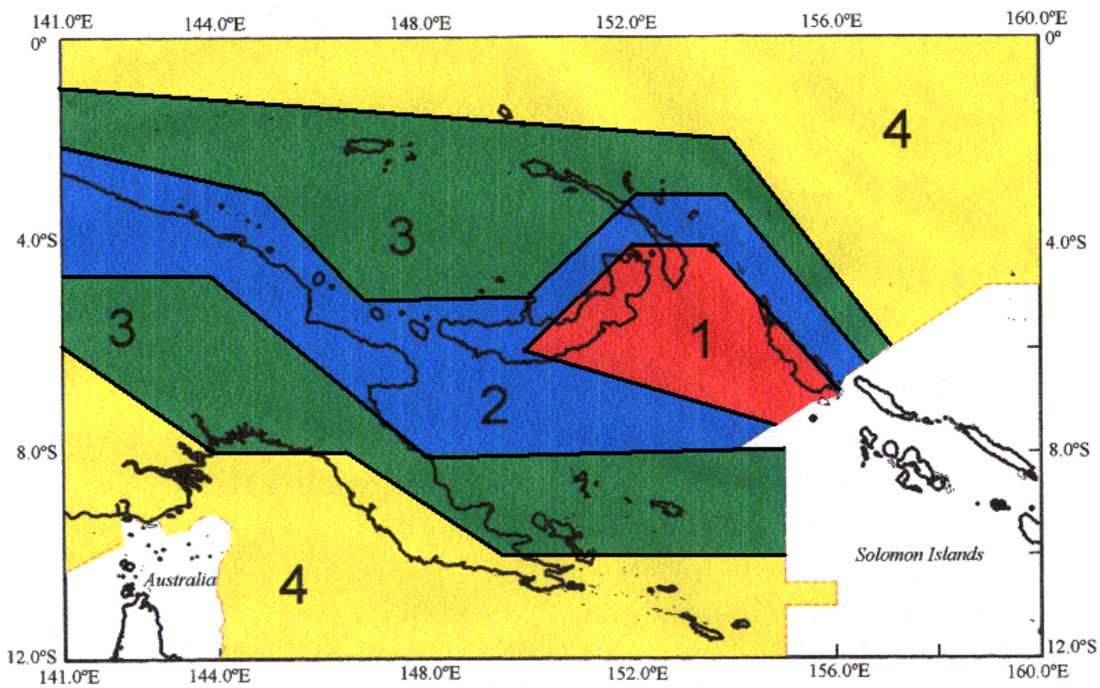

Figure 3. Seismic Zones for building construction in PNG: zone 1 included accelerations of 0.68g or greater, zone 2 accelerations of 0.54g – 0.68g, zone 3 accelerations of 0.4g-0.54g and zone 4 accelerations less than 0.4g.

The zoning boundaries should correlate closely with the distribution of shallow seismicity. Previously missing in the determination of zones was the use of geology (including Quaternary faults) and geophysics data, particularly gravity and magnetics, and geodesy data including GPS deformation measurements. These data will be combined with the seismicity data to help determine the seismic zones.

Some boundaries of seismic zones should continue across seismic gaps, which may not have experienced significant activity in recent years because of temporal clustering. Just as important, the seismic zoning map should continue across political boundaries - something lacking in the current map, especially between PNG and West Papua in Indonesia.

Problems faced and the way forward

As the nation develops, earthquake activity and the hazard and risk that it poses must be considered in the planning of infrastructure for cities and towns, and in the vicinity of major national project sites. While earthquake hazard is not well quantified, it is not easy to mitigate the effects of earthquake shaking. To achieve this, there needs to be acquisition and deployment of proper instrumentation that will record both weak and strong motion, covering the entire region.

Difficulties in communication and transport, and the relatively high density of instrumentation required to resolve the complex geology, increase the cost of improved seismograph networking to levels well above normal, both for installation of the equipment and for routine operation. Not one single attenuation relationship can be expected to suit the whole of PNG (Ripper, 1992), as the region is so complex. Things can be made easier though, such as by learning from the work of experienced institutions abroad (such as in Australia), and acquiring knowledge and expertise, through collaboration. Spence (2007) correctly suggested sharing of resources and expertise available in the richer countries with those most in need of help.

At different levels of government in PNG, not enough effort has been made to provide funds for earthquake monitoring and research, and little thought has been given to contributions from the public purse to fund life-saving research work. There are reasons for this, although not necessarily excuses. Firstly, the country lacks sophisticated economic management and is consequently poor - despite having abundant natural resources. Secondly, not enough awareness is being raised at the country's top executive levels about earthquake hazard and risks. An additional reason may be that when a high percentage of workers are not adequately trained, poor management has often influenced decision-making. It is noted that when the top executives are not educated about the consequences of earthquakes, decisions have been made against the efforts given to provide earthquake monitoring and research for risk mitigation.

Conclusions

Funds provided by the Australian Government have allowed this project to start addressing the issues discussed. The assistance includes showing how developed countries undertake earthquake hazard and related studies, and the economic factors involved. The objectives are obviously to save lives and minimise the enormous cost (social and economic) of such destructive events as earthquakes, tsunamis and floods.

Earthquake hazard and earthquake risk mitigation is important in a country so vulnerable to earthquake occurrence and shaking, where the economy could collapse in a single event. Since PNG is located in a tectonically active region, the chances of such disastrous events occurring are high, and the risks will increase as the country continues to develop.

This project aims to develop preliminary quantified seismotectonic models for the region, and to compute earthquake hazard estimates at selected locations. This will assist in our endeavours to replace the out-of-date hazard map, and the current earthquake building code developed in the 1970s. Valuable comments on the inappropriateness of the code have been made but not yet taken onboard.

For a more detailed review of the earthquake hazard map, adequate and more reliable local data is required. An early component of the project comprised the upgrade of the PMGO earthquake catalogue using the best available databases from the International Seismological Centre and the National Earthquake Information Centre of the United States Geological Survey. The ultimate development will require a network of seismic instruments recording both weak and strong motion, covering the entire PNG region.

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