EARTHQUAKE HAZARD OF PORT MORESBY, PAPUA NEW GUINEA: AN INTRA-PLATE SETTING

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ABSTRACT

The Papua New Guinea (PNG) region experiences relatively high seismicity. Therefore in order to adequately address the high rate of earthquake occurrence, as demand for infrastructure increase with the rapid growth of the nation, seismic source zones throughout the region were identified. In the 1970s when the Earthquake Loading Code was developed, there was a problem with the lack of strong motion data for determination of suitable attenuation relationships and thus the determination of ground accelerations from local and distant earthquakes. In the seismic zoning map Port Moresby was identified to be in the lowest seismic zone.

This current work is based on the best available data and up-to-date methods not available then, and will outline the complexities involved and some possible solutions.

No significant earthquake has occurred within 200 km of Port Moresby but there were four in the distance range 200-300 km from Port Moresby. Two magnitude 6+ earthquakes occurred within 100 km of Port Moresby and six magnitude 6+ earthquakes occurred within 200 km of Port Moresby since 1900.

Port Moresby is situated on the northern India-Australian Plate and is in a region of relativitely low seismicity. However, the city and the Papuan Peninsula have a history of felt tremors generated by distant earthquakes in the New Britain Arc and Trench (subduction zone). The closest distance of the subduction system from Port Moresby is about 300 km.

INTRODUCTION

Port Moresby has experienced increased growth in recent years, especially in the sectors of building construction and infrastructure development. Disastrous effects from earthquake induced shaking of near and far field seismic zones cannot be ignored. Earthquake provisions within the existing earthquake building code must be updated and properly regulated by authorities, to ensure proper planning and mitigation against the impacts of strong earthquakes occurring as close as 50 km to Port Moresby.

As the city grows, concerns will be raised regarding land acquisition and so the city planners will resort to encouraging vertical growth. The simple fact of growth will see infrastructure development as not experienced before. Adequate engineering will be required for earthquake building and design.

Objective

This paper examines seismic hazard in the neighbourhood of Port Moresby, in terms of earthquake return periods and probabilities of occurrence. The adoption of suitable attenuation relationships was important for Port Moresby's firm soil and bedrock foundations. The ground shaking results not only from large earthquakes more than 200 km away but also from smaller earthquakes occurring as close as 50 km from Port Moresby.

Overview

Port Moresby City is situated on the southern coast of mainland PNG, on the fringes of the main plate boundaries which trend NW-SE. The city is the National Capital of PNG where the various arms of Government are located, as well as all the supportive government ministries and departments. It is undoubtedly the nerve centre of the country.

Port Moresby is also the centre of business and all related functions of the private sector. It is also where most foreign envoys and missions reside.

A large damaging earthquake in the neighbourhood of Port Moresby would be disastrous not only for Port Moresby and its residence but the impacts will be felt country-wide, and in the lower levels of government where services will be adversely affected. Both distant major earthquakes, such as those occurring more than 200 km from Port Moresby, and smaller closer events within 100 km can impact on the civil infrastructure that exists in Port Moresby. This will in turn impact on the operation of the government, the economy, and social and community services.

Figure 1 shows Port Moresby in relation to the generalised tectonic configuration of the PNG region. The relative motions of the plates have been determined by Johnson and Molnar (1972), and recently revised by Tregoning *et al*. (1998, 1999, and 2000). Port Moresby is situated south of the northern edge of the India-Australia Plate which parallels the strike of the Owen Stanley Range, along the Owen Stanley Fault system and astride most of the Papuan Peninsula.

SEISMOTECTONIC ZONES

Port Moresby is located at the southern fringe of the seismically active part of PNG. The closest earthquake zones to Port Moresby are the Papuan Peninsula zone, which comprises earthquakes occurring in the Owen Stanley Fault system, and the Menyamya zone, in which earthquakes result from the southward subduction of the Solomon Plate beneath the Papuan Peninsula. Farther north, shallow and deep earthquakes are associated with the northward subduction of the Solomon Plate beneath the Huon Peninsula. Earthquakes also occur beneath the western Solomon Sea, and beneath eastern New Guinea and New Britain. The seismicity of the region is shown in Figure 1.

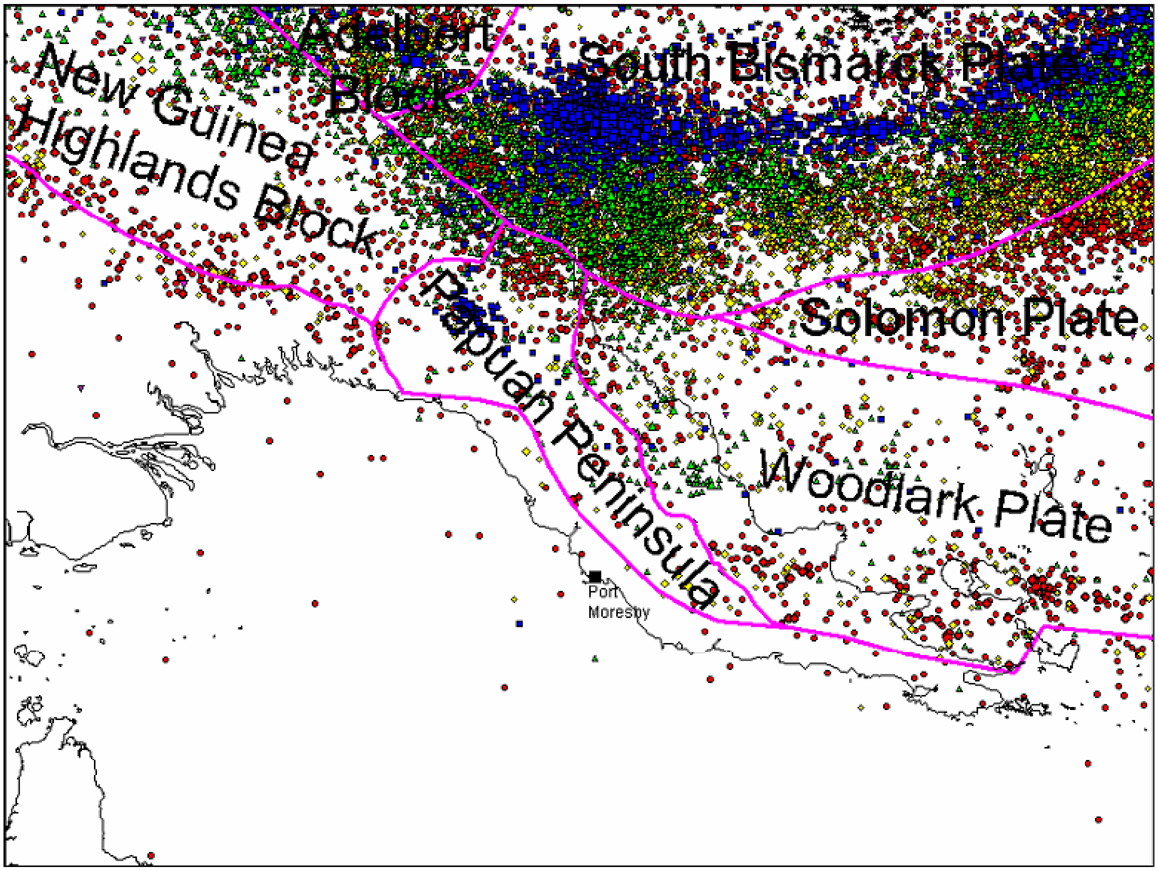

Figure 1. Seismicity of the Port Moresby and southern PNG region, superimposed on the generalised tectonics (purple lines) of Anton (2009) and Anton et al. (2008).The major India-Australian Plate is to the south and southwest. Red circles denote depth range 0-35km, yellow diamonds denote depth range 35-70km, green triangles denote depth range 70-150 km, blue squares denote depth range 150-300k,m purple inverted triangles denote depth range 300-500km and black stars denote depths greater than 500km.

Owen Stanley Fault System

Earthquakes have occurred along the length of the Owen Stanley Fault System, including the Timeno and Gira Fault zones, except in the central region including the Gira Fault where only scattered magnitude 4 earthquakes have occurred. This is the section of the fault system closest to Port Moresby.

The seismicity along the Owen Stanley Fault system includes magnitude 6 earthquakes, but none of magnitude 7 or more. The central part of the fault system closest to Port Moresby is an apparent gap in the seismicity, but being part of the active Quaternary Fault system, it could experience a major earthquake, and the consequences must be considered.

The north-western side of the Peninsula also contains Quaternary fault systems. Faulting at Cape Possession, between Kerema and Port Moresby, is associated with the Aure Fold Belt. Two earthquakes of magnitudes 5.3 and 5.2 respectively occurred 24 minutes apart at 1336 and 1358 UTC near Bereina, 73 km NNW of Port Moresby on 15 September 2007. The earthquakes shock the region including Port Moresby. East and southeast of Port Moresby on the southern side of the Owen Stanley Range, earthquakes on the Southern Fall and Kemp Welsh systems could cause damage in Port Moresby. No earthquakes have occurred close to the Kemp Welsh fault. However, several very small earthquakes have occurred close to the Owen Stanley Range Southern Fall fault including a magnitude 6.2 earthquake on 9 March 1979 in the lower crust at a depth of about 46 km which could indicate that the Quaternary fault systems of the Papuan Peninsula, including the Owen Stanley Fault System, extend deep into the crust. The earthquake has been described by Ripper, McCue and Wolter (1980), Ripper and McCue (1981b), and Ripper and Moihoi (1996). The isoseismal map of this earthquake is shown is Figure 2 (Ripper et al., 1980).

About 20 years later on 29 June 1999 at 0550 UTC a magnitude 6.0 occurred at shallow depth beneath Mt Obree, about 70 km east of Port Moresby. The earthquake shock the region including Port Moresby, but no damage was reported.

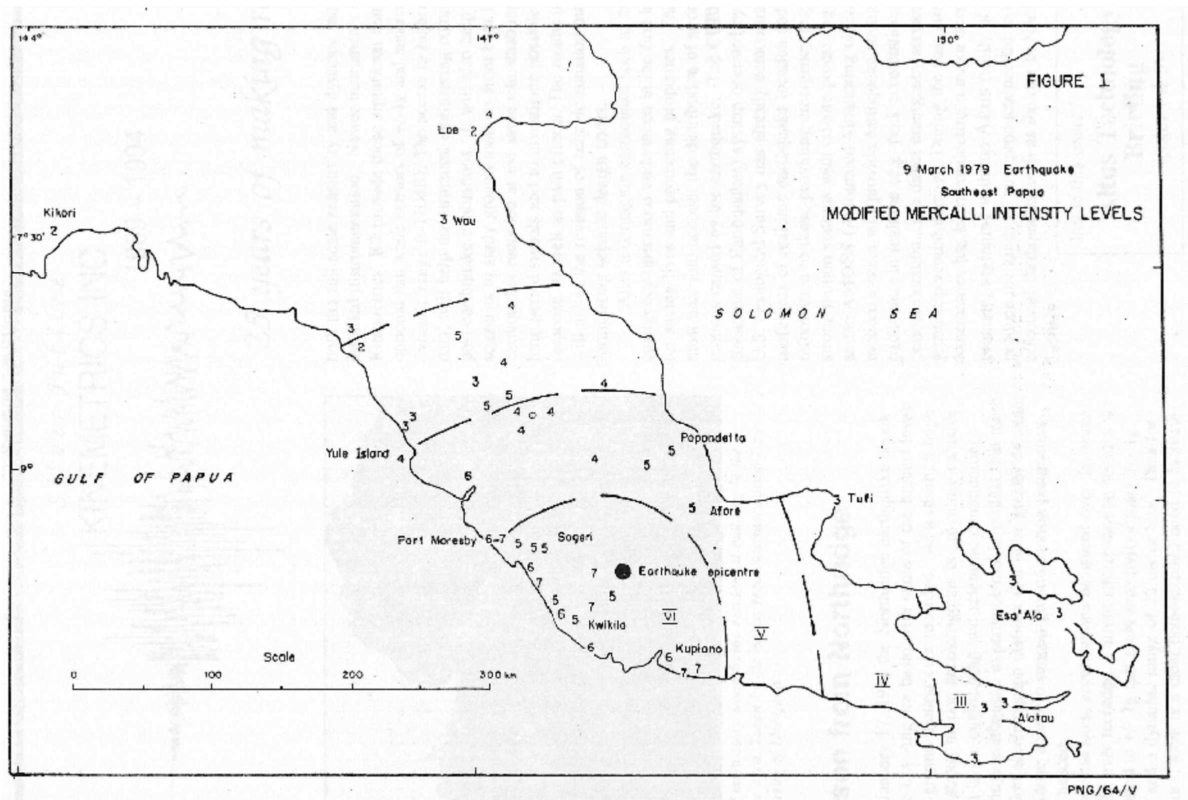

Figure2. Isoseismal map of the 09 March 1979 Port Moresby earthquake (from Ripper et al., 1980).

Large earthquakes can be expected to occur again in the Southern Fall fault area. In the northwest section which reaches the Huon Gulf in the vicinity of Salamaua, magnitude 5 earthquakes are common but there have been no recorded magnitude 6 earthquakes.

In the southeast section southwest of Mt Victory in the zone including the Musa River, several magnitude 5 earthquakes and one magnitude 6 earthquake have been recorded. A magnitude 6.2 earthquake occurred on 16 September 1976, the first anniversary of PNG Independence. It was moderately felt in Port Moresby (Ripper *et al*., 1980).

The Quaternary fault extension into the Abau area of the southeastern end of the Papuan Peninsula is not matched by contemporary seismicity. In this area, the Peninsula is virtually aseismic. Instead, the seismicity is occurring to the north in the Goodenough Bay and Goodenough Island regions. Magnitude 6 earthquakes could occur in the aseismic Abau area of the Papuan Peninsula.

Seismic activity of the Owen Stanley Fault System as a whole is ongoing, but the largest recorded earthquakes are only of magnitude 6.2. We assess the maximum credible earthquake on the Owen Stanley Fault System to be of magnitude 7.5.

Effect of intermediate depth earthquakes

Large earthquakes occurring at intermediate depths beneath the New Britain Trench and beneath eastern (and northern) New Guinea are associated with subduction of the Solomon Plate to the north and west.

Deep earthquakes beneath Long Island eastern New Guinea are usually widely felt through the Highlands, some strong enough to cause damage. With deep earthquakes from this region, the energy is apparently channelled up through the sinking Solomon lithospheric plate slab southwest into the Highlands, as suggested by Denham (1971). The slab is the western segment of the Solomon Plate which is subducting westward and northward beneath the New Guinea/Bismarck Volcanic Arc.

Intermediate depth events at 120 km beneath the Sepik Valley indicate the existences of lithosphere, either as a horizontal plate or as fragments, sinking into or being assimilated into the mantle (Denham, 1975), the sunken lithosphere the remnants of a once larger Solomon Plate (Ripper and Letz, 1991).

Depending on wave travel paths and site conditions, as well as factors such as geometric spreading, scattering and attenuation or amplification, shaking at distant sites such as Port Moresby may cause distress in high rise buildings. There have been numerous cases of such intermediate earthquakes impacting upper levels of high rise buildings in Port Moresby over the years. It is important that buildings are suitably designed to cater for excessive motion such as the P-Δ effect.

EARTHQUAKE DATA

Earthquake intensity

The intensity of an earthquake is determined from its effect on people, buildings, and the Earth's surface. A Modified Mercalli Intensity Scale for PNG is listed by Ripper (1979).

In the Port Moresby region, intensities up to 7 have been experienced. Intensity 7 includes damage to weak or poorly built structures and some village houses. Intensity 8 rates damage to ordinary well built structures, but not to structures that have been properly designed and built to an earthquake code. Several major structures in Port Moresby sustained damage during the 1979 earthquake.

There have been no reports of landsliding or ground subsidence in the city, but they were observed in the neighbourhood especially in areas of the Owen Stanley Range and the Papuan Peninsula.

Seismic Data

Major earthquakes, magnitude 7 and one magnitude 8 earthquake, have occurred at an epicentral distances of 250-350 km from Port Moresby. Earthquakes occurring more than 500 km of Port Moresby are not used in this study.

Two magnitude 7 earthquakes were recorded beneath Menyamya (7.2 in 1951 and 7.3 in 1963), one magnitude 7 earthquake occurred in the southern part of the Huon Zone (7.2 in 1916), and four magnitude 7 earthquakes were recorded from the western Solomon Sea zone (7.2 in 1902, 7.0 in 1913, 7.5 in 1947, and 7.2 in 1966). The largest known earthquake of the region was the *great* earthquake of 1906, Ms 7.8, Mw 8.0, which occurred under the western Solomon Sea at latitude 7.0°S and longitude 149.0°E, about 350 km north of Port Moresby.

Closer to Port Moresby, beneath the Papuan Peninsula, the strongest earthquakes have been magnitudes 6.0 in 1972, 6.2 in 1976, 6.0 in 1978, 6.2 in 1979, 6.0 in 1991, and 6.0 in 1999. The 1979 earthquake (Ripper, McCue and Wolter, 1980) only 90 km away was felt strongly in Port Moresby and caused structural damage to a number of new and older buildings. The most dramatic damage was the buckling of several heavy concrete slabs in the suspension roof of the National Museum at Waigani. At the Department of Mining Building in Konedobu, a 2 cm wide crack appeared at ceiling level on the floor between an old internal war-time vault and the more recent office complex. The estimated maximum intensity at several locations in Port Moresby was 7 on the Modified Mercalli scale (MM7).

Maximum Credible Earthquake Magnitudes

Maximum earthquake magnitudes previously determined by Ripper and Letz (1993) for their seismic zones near Port Moresby were: the Papuan Peninsula, 7.5; Menyamya, 7.5; Huon Peninsula, 8.0 and Western Solomon Sea, 8.0. Based on the occurrence of these large earthquakes the maximum credible earthquake magnitude in the seismic zones near Port Moresby is taken to be 8.0.

However, the maximum credible earthquake for the tectonic seismic zones near Port Moresby are (from Anton, 2009) 0.5 of a magnitude unit lower, there is no geological evidence of a great event here.

Figure 6 shows the deaggregation plot for 1.0 second period motion at a return period of 975 years for Port Moresby (from Anton, 2009). The corresponding ground acceleration is a relatively low 0.07 g. The figure shows three main source of hazard, including nearby events of moderate sized magnitudes, large events at distances of 20 to 500 km, and some contribution from great earthquakes at distances of 500 km and beyond (cumulatively plotted at 500 km).

Seismic data analysis for the Port Moresby region

Eight seismic zones in layer 1 of the PNG1 seismotectonic model were combined with five in layer 2, six in layer 3, three in layer 4 and 1 in layer 5. The parameters of the source zones were extracted from the PNG1 model (Anton, 2009; Anton and Gibson, 2008).

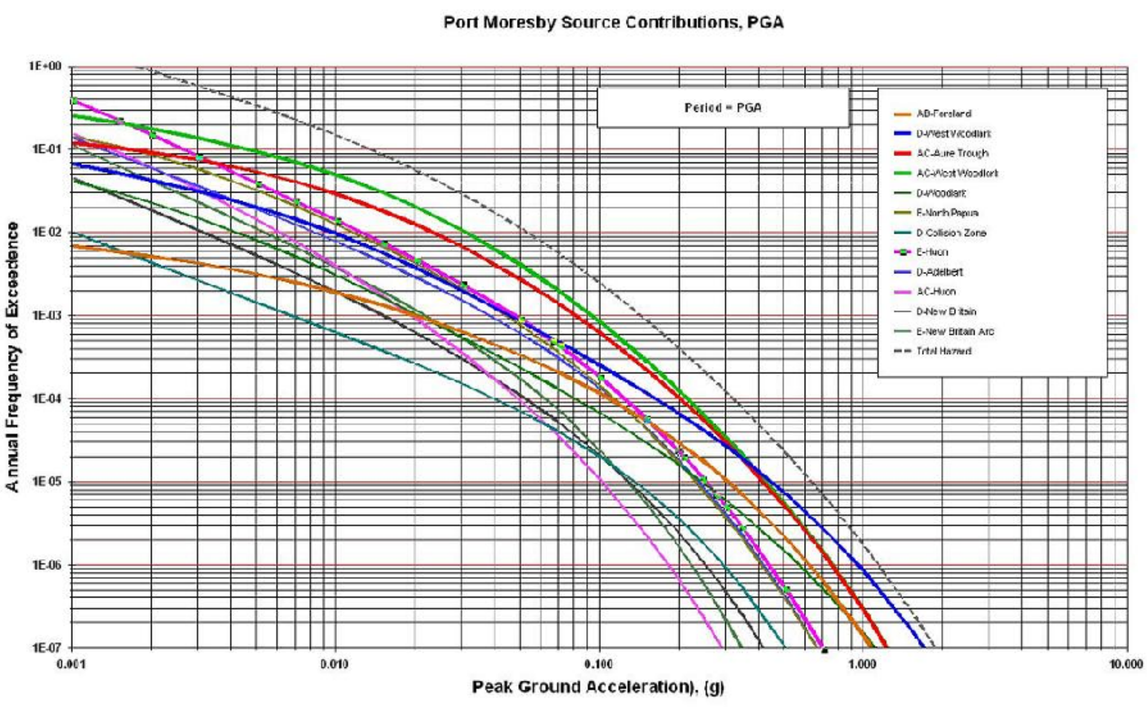

Figure 3. Seismic hazard contributions in Port Moresby from source zones within 500 km.

Port Moresby lies south of the main seismic zones of PNG and so the contributions to the hazard are those originating mostly from shallower events to the north, east and west. However, the Capital City is often shaken (especially on the top floors of high rises) by earthquakes occurring deep beneath north-eastern New Guinea and New Britain. These are at distances of more than 300 km. To the south is the stable and inactive Australian craton, where the hazard is low. Australia is known for its' shallow intra-plate earthquakes though, and this must be given some consideration to zones on the craton, especially those bordering the foreland platform.

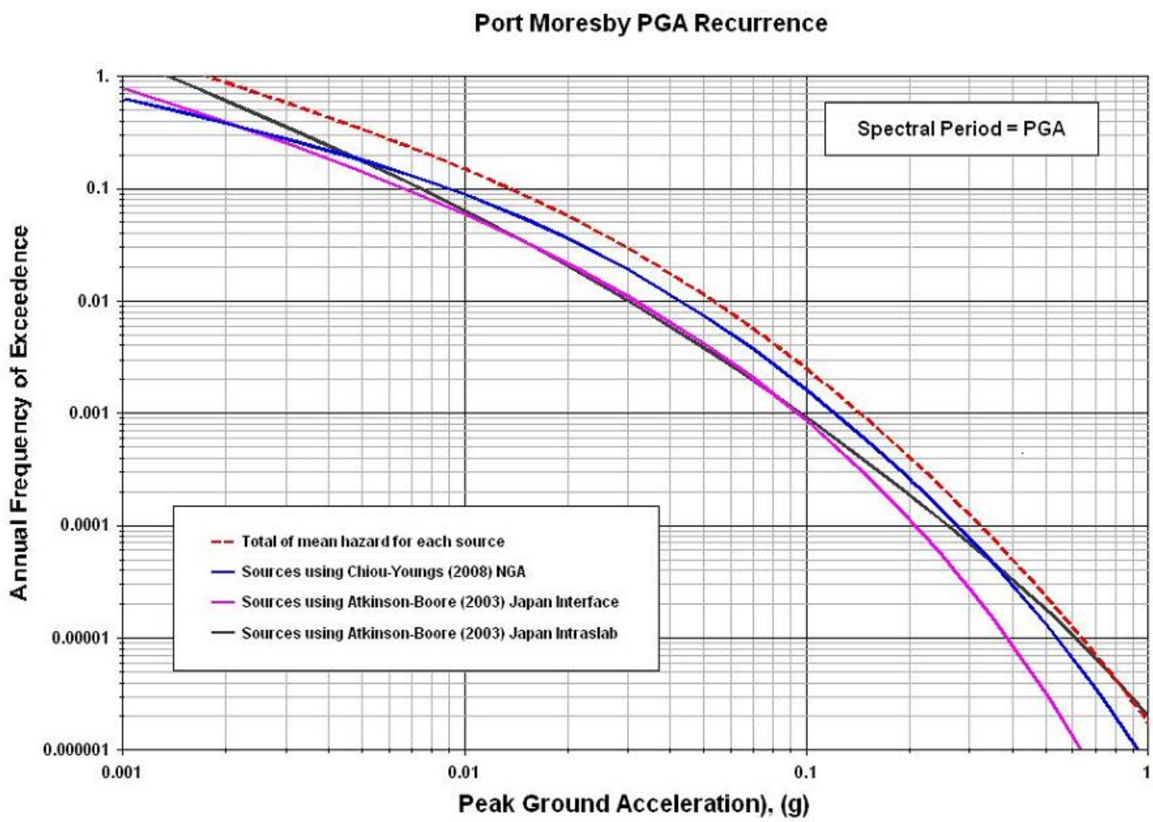

Figure 4. The Frequency of Exceedence at Port Moresby for PGA on bedrock, magnitudes 5.0 and higher at varying return period.

The peak ground acceleration is numerically equal to the response spectral acceleration at near zero period, on the left land side of each of the plots. Motions are for bedrock, considering magnitudes 5.0 and higher.

The 100, 475 and 1000 yr peak ground accelerations (g) are given in the following table

100	475	1000
0.05	0.09	0.35

The uniform probability response spectra for return periods of 475 years, 3000 years and 10,000 years are shown in Figure 5. Spectra for other return periods can be found by re-calculation. For Port Moresby, the deaggregation plot of 1.0 second for a return period of 975 years (Figure 6) shows that most of the contributing earthquakes originate locally.

Overall magnitude 6 earthquakes near Port Moresby are relatively frequent while maximum credible magnitude earthquakes of 7.5 have a long recurrence rate.

Figure 4 shows that the peak ground acceleration at Port Moresby has contributions from shallow or crustal seismic zones using the attenuation of Chiou-Youngs (2008), and higher accelerations may originate from the intra-slab zones, using the attenuation function of Atkinson-Boore (2003).

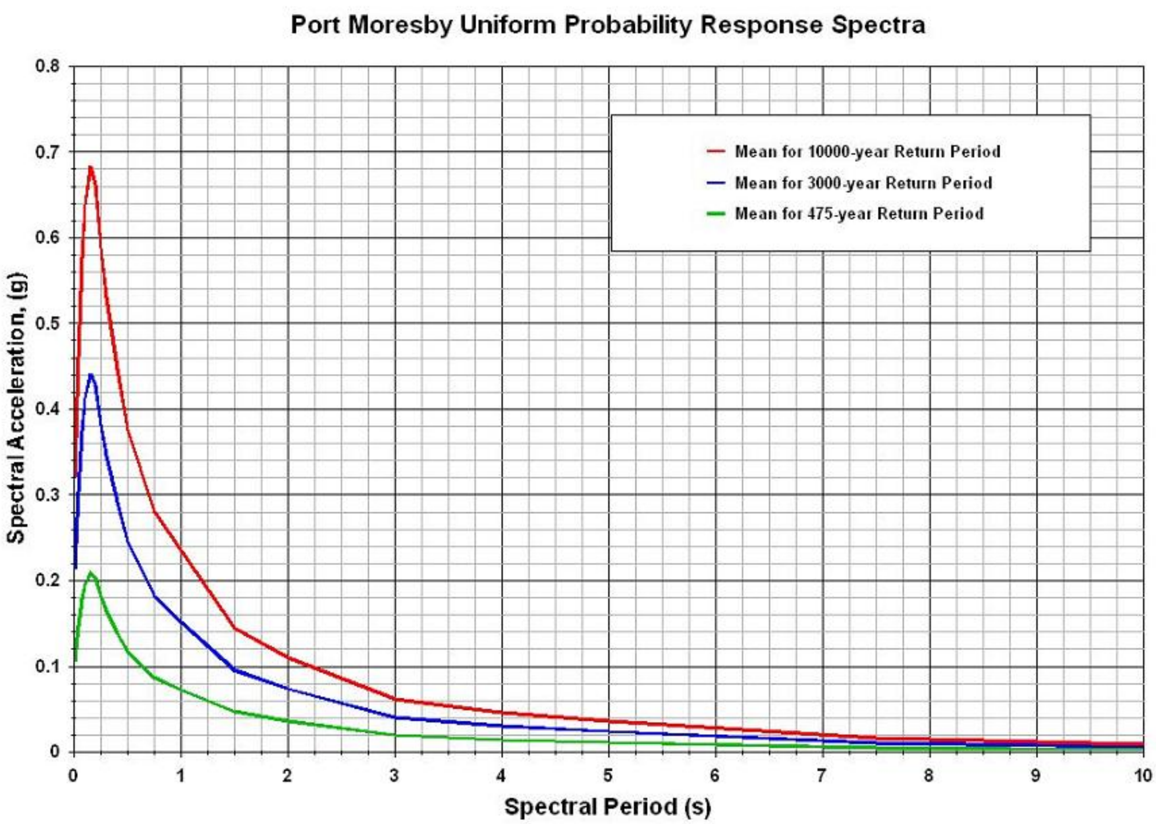

Figure 5. Uniform probability response spectra for Port Moresby, for bedrock, magnitudes from 5.0 and source zones within 500 km of Port Moresby.

Figure 5 shows the uniform probability response spectra at Port Moresby for bedrock, using magnitudes from 5.0. The peak ground acceleration is numerically equal to the response spectral acceleration at near zero period. The spectra for other return periods can be found by re-calculation, or approximately by interpolation.

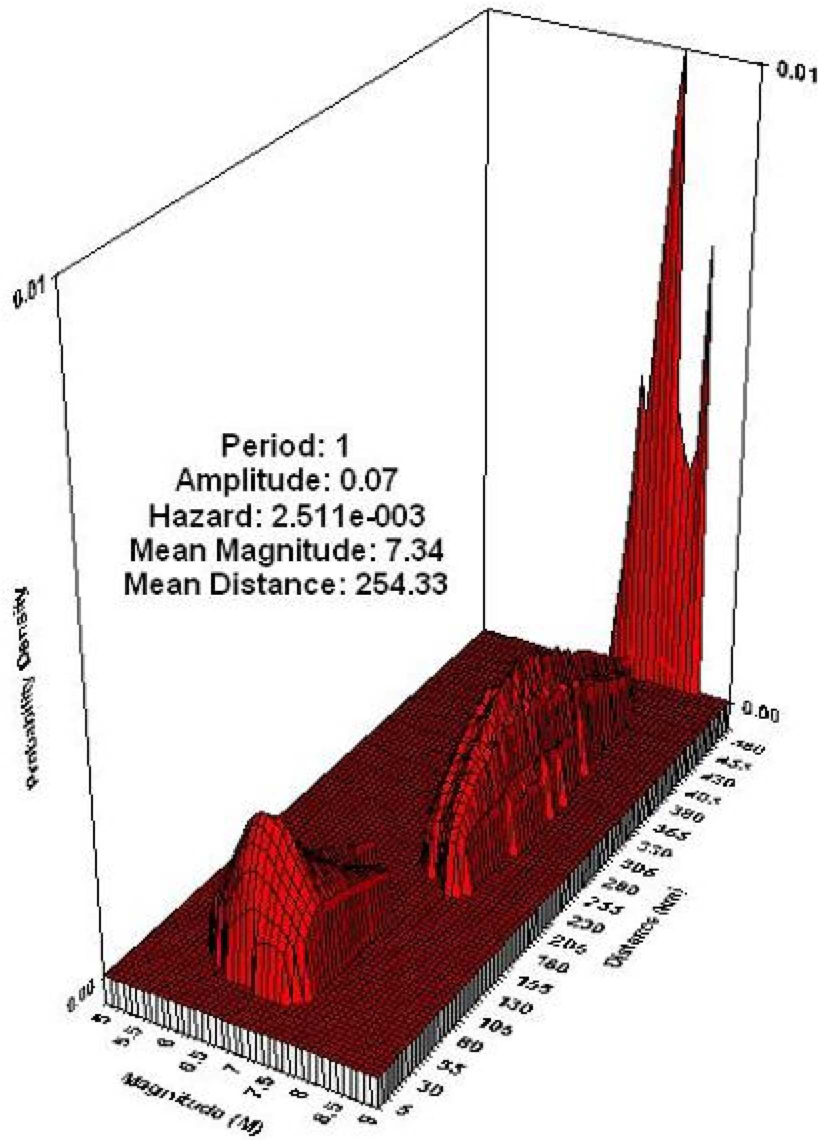

Figure 6. Magnitude- distance deaggregation for all source zones within 500 km of Port Moresby.

Comparing with Maximum Intensities recorded in Port Moresby

An analysis of Port Moresby maximum intensities observed since 1953 (MM6 since 1900) are plotted in Figure 7. A least square fit is obtained as indicated, with R^2 of 0.95.

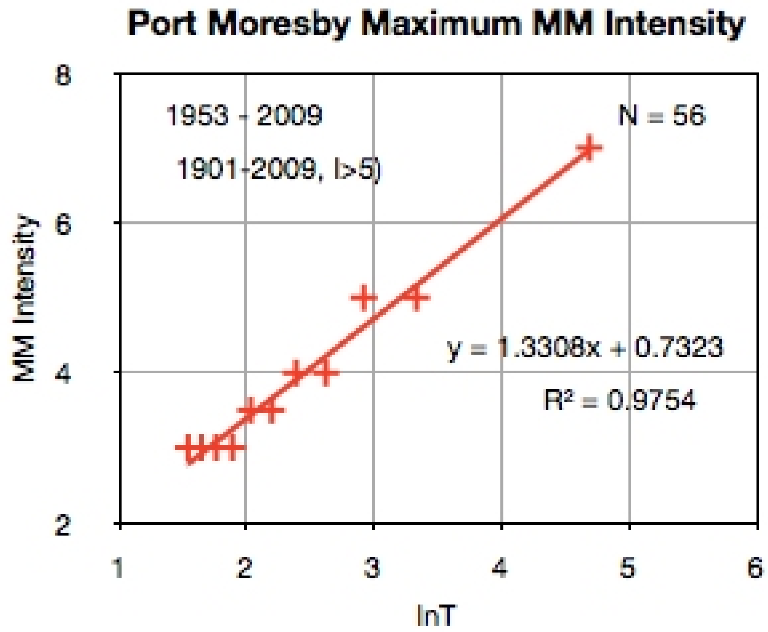

Figure 7 MM Intensities in Port Moresby plotted against the natural log (ln) of Return Period T (years)

The extrapolated maximum intensity for a return period T of 475 years (lnT = 6.2) is about MM9 (see the accompanying paper by McCue) which is interesting but not useful for design. Its main use is for comparison with other areas where the hazard is better defined.

Recorded earthquake accelerations

An acceleration attenuation relationship for Port Moresby has not been derived as there is a critical lack of data (recorded ground accelerations). Only one ground acceleration, of 0.011 g has been recorded. This was from an earthquake of magnitude 4.4 at 134 km distance. At the time of the magnitude 6.2 earthquake of 9 March 1979, no accelerograph was operating in Port Moresby.

In a previous study, Ripper (1992), used equation 1 for nearby earthquakes (0-50 km), and a second expression 2 derived by Esteva and Villaverde (1973), for relatively flat-lying firm ground and bedrock with no soil cover, and representative of coastal regions, for earthquakes at distances > 50 km. The attenuation relationships are:

$$A/g = 40 \exp(0.8M)/R + 100)^{2.1} \quad (1)$$
$$A/g = 5.7 \exp(0.8M)/(R + 40)^{2} \quad (2)$$

Three recorded earthquake ground accelerations from the Papuan Peninsula, including Port Moresby-Konedobu, are shown in Figure 8.

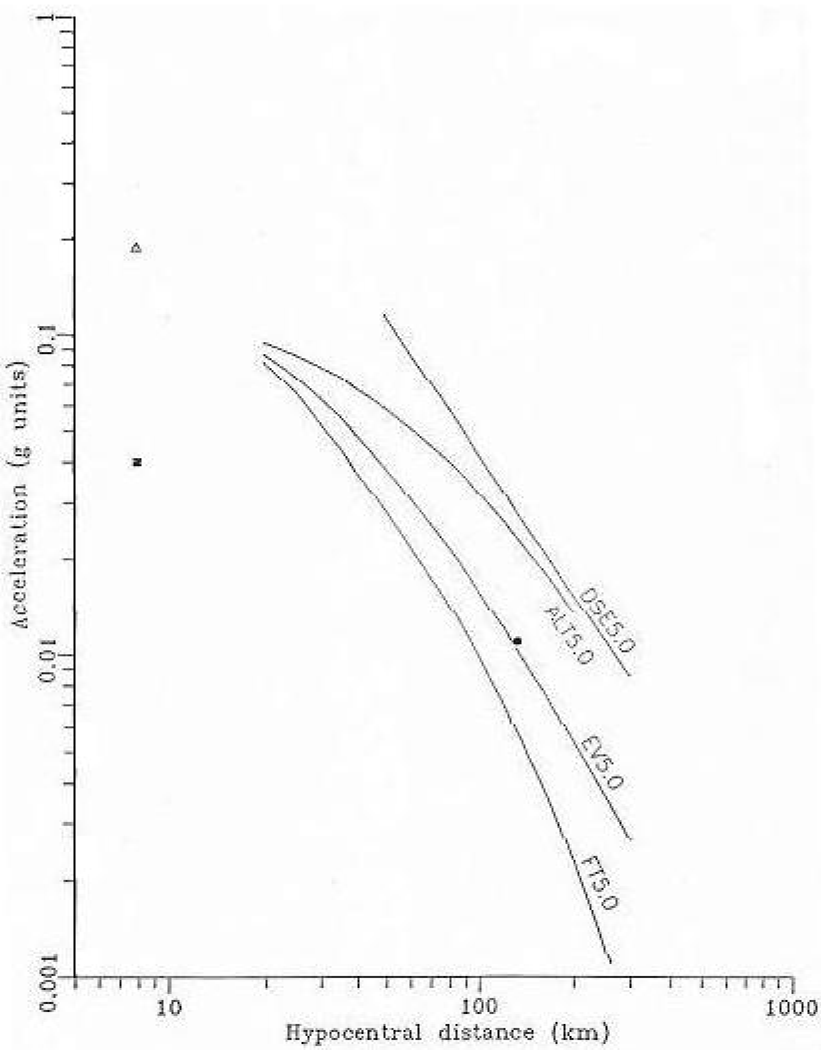

Figure 8. Recorded earthquake accelerations from the Papuan Peninsula, magnitude range less than 5.4, superimposed on the acceleration attenuation curves for magnitude 5.0, Musa Ridge A (soft, elevated), open triangle; Musa Damsite B (rock), solid squares; Port Moresby-Konedobu (rock), solid circle. (From Ripper, 1992).

These are too few to base a hazard analysis on so following Anton (2009) two modern relationships are used for the Port Moresby area. The relationships are by Atkinson and Boore (2003) for subduction zones and Chiou and Youngs (2008) for crustal zones. A combination of these is possible for distances farther than 200 km where subduction zones are encountered.

CONCLUSIONS

The data used in the PSHA to determine the hazard parameters are from the Papuan Peninsula, Menyamya, Huon and Western Solomon Sea seismic zones. However, closer earthquake i.e those that occur within 100 km of Port Moresby are most likely to be damaging. The magnitude 6.2 earthquake of March 1979 which caused building damage and was felt strongly in Port Moresby (MM7) occurred about 90 km east of the city. A second magnitude 6 earthquake from a similar location in 1999 was also felt in Port Moresby. Thus, for building design in Port Moresby, it is recommended that:

(i) a pga of 0.1g be used for the 500 yr bedrock ground motion for normal building design in Port Moresby

(ii) the rock spectra shown in Figure 5 are suitable for design purposes for buildings in Port Moresby

(iii) for tall buildings (above 10 stories), P-Δ effects should be considered using suitable accelerograms of great earthquakes at 350 km distance.

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