# Modelling a great earthquake for the SW Pacific

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**ABSTRACT:** Using accelerographs recordings of two large earthquakes that occurred this year, we have synthesised the possible ground shaking of a great earthquake in the SW Pacific region. Subduction zone earthquakes near Vanuatu (M6.4) and Rabaul (7.5) were used as sub-events to simulate a magnitude 8.5 earthquake, a great but not necessarily greatest earthquake for the region. Green's function simulation is run in a stepwise procedure to increase the size of the sub-event to a larger magnitude event.

The results are especially applicable for use in hazard studies, as a design earthquake for dynamic testing and could also be incorporated in local building codes in the SW Pacific.

## 1 INTRODUCTION

Countries of the Southwest Pacific have the highest earthquake hazard on planet Earth and a growing earthquake risk as development pushes ahead. Unfortunately there are no site specific building codes and developers are using whatever they are familiar with; US, European, New Zealand or SE Asian codes to impart some level of safety to the buildings. What seismic coefficient is used seems to be decided by the developer. This is compounded by the lack of strong motion data so even if they were keen to use local information, no locally-specific design ground motion data are available.

Recently the first useful data have been recorded in the region thanks to an Australian Government initiative in Rabaul, Papua New Guinea and to a private installation by a citizen scientist in Vanuatu, in that country as part of an Australian aid mission to help Vanuatu recover from the impact of a tropical cyclone.

## 2 THE DATA

### 2.1 Vanuatu earthquake

A large shallow earthquake 145km north of Vanuatu was recorded on a PSN accelerograph module soon after it was installed at Port Vila on the island of Efate in early 2015. The shaking was reasonably strong in the capital city still recovering from the cyclone but not everyone was awakened and no additional damage was reported.

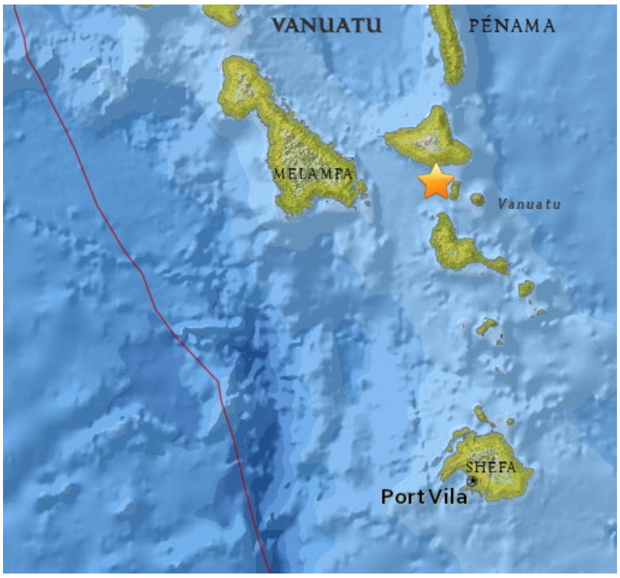


**Figure 1** Location of the large shallow thrust earthquake (orange star) recorded on an accelerograph in Port Vila. Location details according to the USGS are: 2015-02-19 at 13:18:32 UTC, Vanuatu 16.43°S 168.15°E depth 10km, Mw6.4

The earthquake mechanism is a classic thrust oriented east-west perpendicular to the Pacific Plate boundary to the west.

The site geology has not been studied in detail but according to Howarth (1983): *Efate is a Late Pliocene to Pleistocene volcanic island. A series of elevated reef limestone terraces are widely preserved from sea level to heights of over 600m. Around Vila the topography is dominated by reef limestone terraces which have been uplifted, faulted and tilted. Underlying the limestone is the Efate Pumice Formation which comprises pumiceous breccias and tuffs of the original strato-volcano. The uplifted Holocene reefs varying up to 10m above sea level are a series of uplifted Holocene reef terraces, each produced by faulting and tilting which is likely to be co-seismic*.

## 2.2 Papua New Guinea earthquake

A major shallow earthquake located 75km southeast of Rabaul shook the town and was recorded on the accelerograph installed by Geoscience Australia at the Rabaul Volcano Observatory.

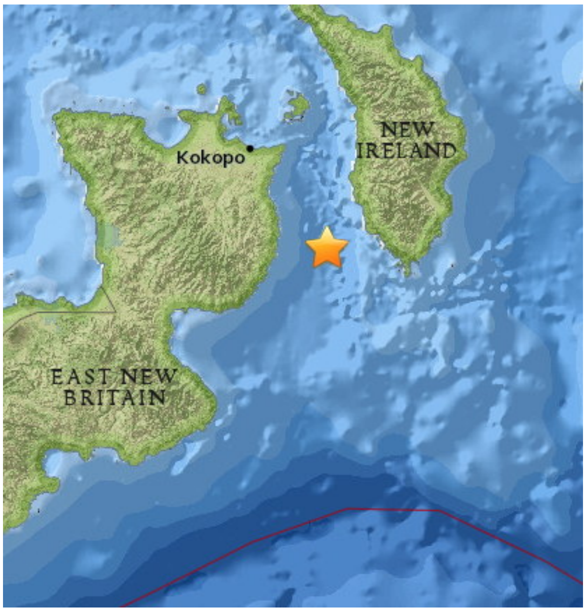


**Figure 2** Location of the large shallow thrust earthquake (orange star) about 75 km SE Rabaul, Papua New Guinea. Location details according to the USGS are: 2015-3-29 at 23:48:31 UTC, Papua New Guinea 4.729°S 152.562°E depth 40 km, Mw 7.5.

The mechanism is a shallow thrust, the principal stress direction north-south and perpendicular to the Solomon Sea Plate boundary to the south.

The Observatory is on a tuff ridge radiating from *The Mother* volcano, the tuff overlying volcanics.

It doesn't take long to collect useful strong motion data in countries of the Southwest Pacific due to frequency of the large earthquakes.

## 2.3 Seismic Recordings

Figure 3 shows the 3-component records of the magnitude 6.4 earthquake at Vanuatu with the related frequency spectrum (Hz). The vertical component of the seismogram contains higher frequencies between 1.5 and 5 Hz than the horizontal components, which are influenced by the geology of the island.

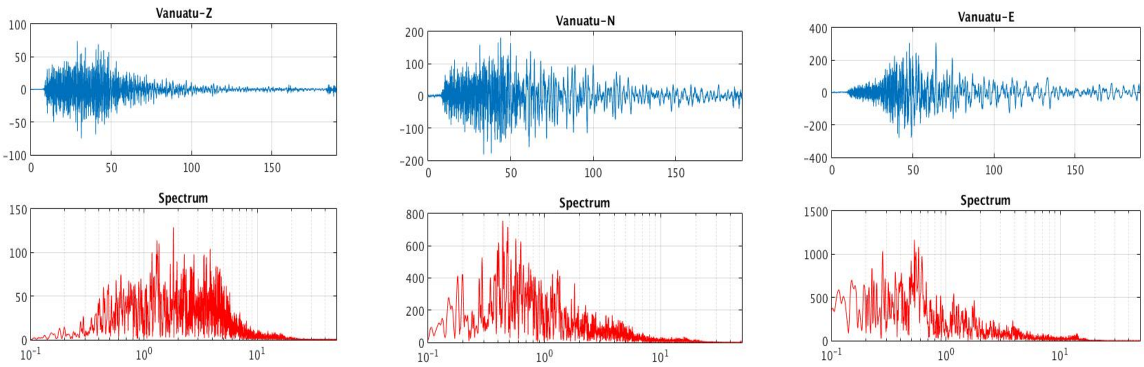


**Figure 3** Recorded accelerograms at Vanuatu station of the earthquake on 2015-02-19 with the corresponding Fourier Amplitude Spectra for each component (Hz).

Figure 4 shows the 3-component records of the magnitude 7.5 earthquake at Rabaul with the related frequency spectrum (Hz). Not much energy can be seen for the lower frequencies between 0.1 and 1.5 Hz, that is indication of the local geological characteristics.

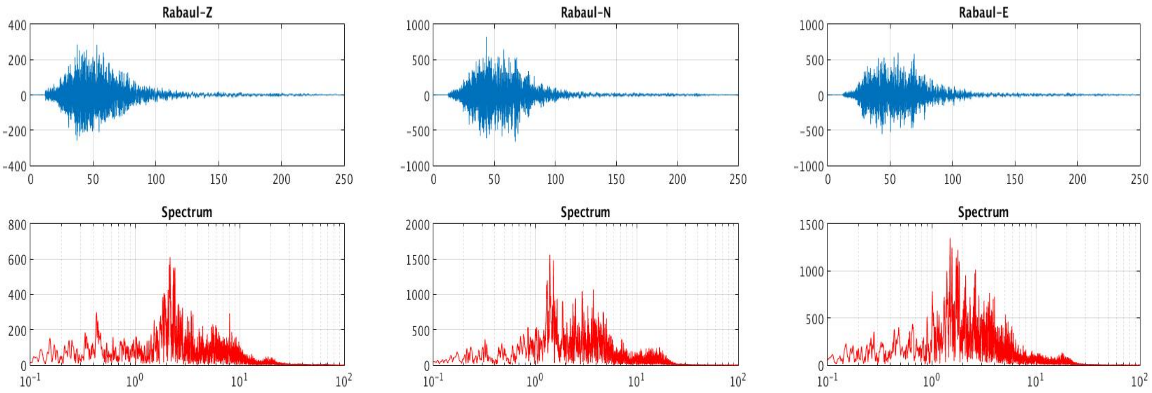


**Figure 4** Recorded accelerograms at Rabaul of the earthquake on 2015-03-29 with the corresponding Fourier Amplitude Spectra for each component (Hz).

Figure 5 is a log-log display of the Fourier Amplitude Spectra of the accelerograms at Vanuatu and Rabaul for all three components versus period in seconds. The longer periods of the Vanuatu recording are visibly distorted, perhaps by the instrument filtering.

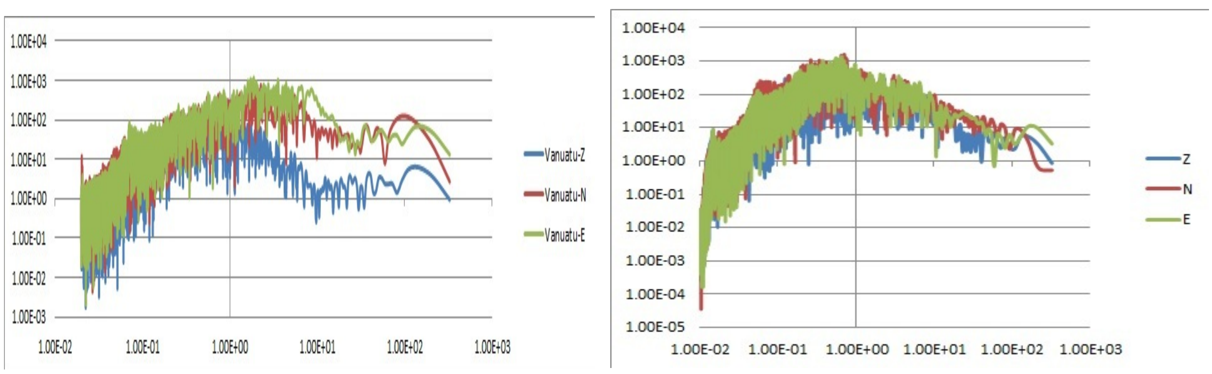


**Figure 5** Fourier Amplitude Spectra of the accelerograms at Vanuatu (left) and Rabaul (right) for all three components versus period in seconds.

The accelerograms will be influenced by the regional geology and crustal structure if known. Local monitoring can be used to develop crustal models; by monitoring mine blasts at Panguna Bougainville and local earthquakes, McCue, 1987a and 1987b, did just that. The strong motion results can then be used elsewhere where there is a similar crustal model and tectonics. In our case Port Vila and Rabaul are both volcanic arc locales on oceanic crust bordering major active plate boundaries, similar to most of the islands between PNG and Tonga so any recordings such as these should be applicable there.

## 3 THE GREEN’S FUNCTION STRATEGY

### 3.1 The Method

The basic idea behind the Green’s function method is to interpret the instrumentally measured response of a small seismic event as an empirical Green's function and use it to simulate a larger earthquake. The sub-event is summed multiple times (main earthquake area/subevent area) so that a larger earthquake of the same source characteristics and distance is synthesised. The sub-events are distributed over a fault area that is empirically defined. The summation process consists of a series of time delays between the sub-events that simulate a rupture propagation across the hypothetical fault. The number of sub-events and their summation are proportional to the scaling between earthquakes of different magnitude. The site effects are taken into account because the waves from the sub-event and the main earthquake would have passed through the same subsurface.

This method requires general summation patterns in order to simulate realistic earthquake records. There are many approaches for summing small earthquakes, but basically only two parameters dominate the shape of the waveform: the seismic moment through the peak amplitude and the stress-drop through its frequency. The range of periods having higher spectral amplitudes is expected to be similar to the range of periods of vibration of the designed earthquakes. The other assumptions is that the corner frequency will obey the empirical laws for large earthquakes. The Green’s function method has been successfully applied in simulation of strong ground motion for Australian earthquakes (Jankulovski *et al.,* 1996, Sinadinovski *et al.,* 1996, Sinadinovski *et al.,* 2000, and Lam *et al.* 2003).

### 3.2 Simulation

We decided to first use the Vanuatu record as a Green’s function to model the Rabaul accelerogram and then use the velocity and rupture time history that best matched the observed spectrum to model a great earthquake at approximately 100km distance from a shallow thrust type earthquake.

Figure 6 represents an example of a simulation with twelve sub-events of the Vanuatu record magnitude 6.4 distributed on a fault orthogonal to the source-station path during a rupture originating in the centre and propagating uniformly in all directions with a velocity of about 4km/s.

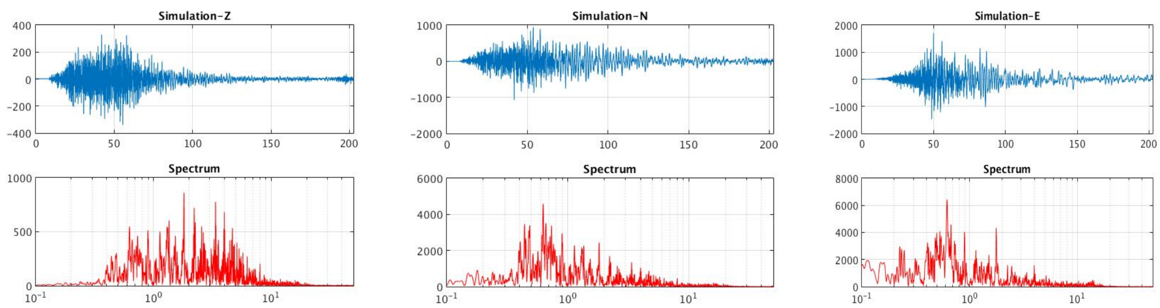


**Figure 6** Synthetic accelerograms at Rabaul of a magnitude 7.5 earthquake using the Vanuatu record magnitude 6.4 with the respective Fourier Amplitude Spectra for each component (Hz).

The summed event of approximate magnitude 7.5 has a broader spectrum as expected and does a very good job across the frequencies 0.5 to 1 Hz that are of interest for civil engineers. Figure 7 is a log-log display of the Fourier Amplitude Spectra of the accelerogram at Rabaul and the synthetic record for all three components versus period in seconds. The longer periods start to drop off at about 3sec period and may be distorted by the instrument filtering and cannot be recovered properly.

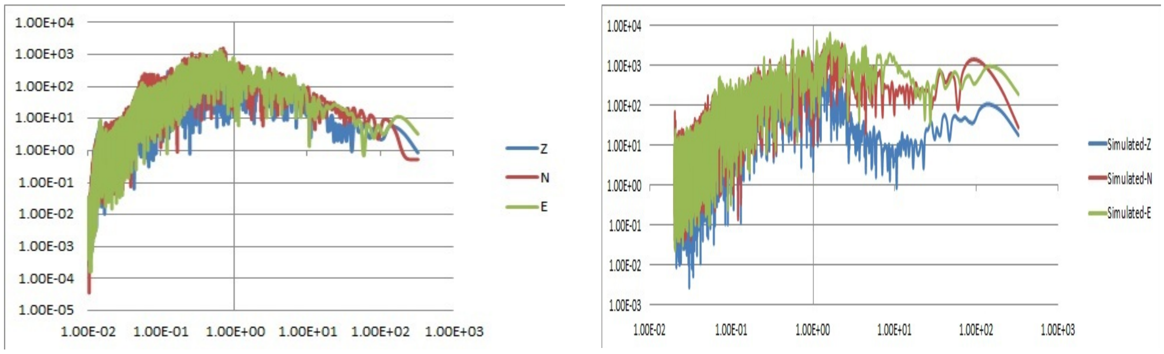


**Figure 7** Fourier Amplitude Spectra of the accelerogram at Rabaul (left) and the synthetic (right) for all three components versus periods in seconds.

In the next stage we simulated a large event of approximate magnitude 8.5 using as the sub-event in the first case - the simulated Vanuatu record and in the second case - the original Rabaul record. Figure 8 is a log-log display of their Fourier Amplitude Spectra for all three components versus period in seconds. It has an even broader spectrum as expected and although it does a fair representation across the periods from 0.5 to 2 seconds. More artifacts appear after 4-5 seconds for the simulation when a synthesized Vanuatu record is used as a sub-event then when the Rabaul record is used, where artefacts appear after 10 seconds and might not be that important for engineering purposes. As before, the longer periods were distorted by the instrument filtering.

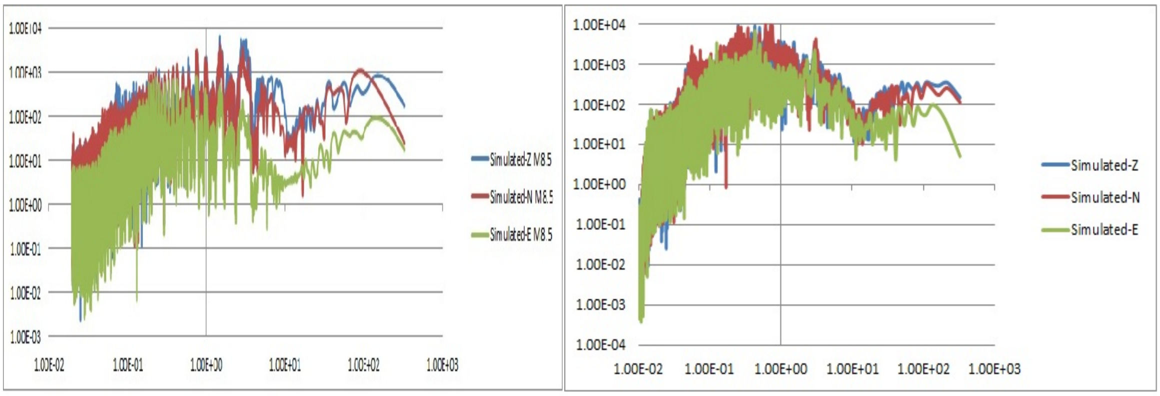


**Figure 8** Fourier Amplitude Spectra of a synthetic representing a great earthquake magnitude 8.5 using synthesized Vanuatu record (left) and Rabaul record (right) for all three components versus periods in seconds.

The range of periods having higher spectral amplitudes in the recorded and simulated earthquakes in this study was in accordance with observations from the literature. Varying the distribution of sub-events along the fault-plane leads to simulated events that look realistic, both in terms of amplitude/duration and frequency content. The synthetics are comparable with the whole earthquake spectrum of dominant periods for the large events.

## 4 DISCUSSION

Earthquake strong motion records are an essential input for dynamic modelling of structures as may be demanded by the local Building Coce. In the absence of quality records of large events, engineers need to find alternative approaches. The Green's function method is one promising approach that uses summation of smaller events up to representative records, taking into account the amplitude and frequency content according to empirical laws. Here we present several waveforms and spectra of candidate design earthquakes based on the recordings made this year at Port Vila Vanuatu and Rabaul Papua New Guinea. Site specific strong motion records are valuable because they incorporate site, source and path effects.

There is nothing unique about any waveform computed (or measured for that matter), it may vary dramatically depending on the rupture velocity and offset time between element fractures though not so much on the direction or starting point of the rupture. Without a recorded earthquake there may be considerable scatter in the computed waveform and spectrum of a scenario earthquake so we recommend that several, perhaps 3 or more, different waveforms are used in the response calculation. These uncertainties are probably no greater than assuming the building damping is 5%, compared with say 1%, a value that is often measured in real buildings. It is interesting to know the scatter of different approaches, since that information is useful in the decision making process for the hazard analysis.

There is no substitute for actual recordings and we urge developed nations in the Southwest Pacific to assist nations there in installing and maintaining strong motion recorders on bedrock and in significant buildings. This should be accompanied with on-site training provided to engineers and seismologists in analysing the recordings and developing appropriate loading codes.

## 5 ACKNOWLEDGMENT

We are most grateful to Chris McCowage who made available the accelerogram recorded on his Port Vila accelerograph and applaud his initiative in installing the instrument there. Geoscience Australia are likewise thanked for making the Rabaul recording available. We encourage the PNG Government to release all recordings made in Rabaul, for the benefit of PNG and the whole SW Pacific.

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