Regional ground motion hazard for liquefaction and landslide assessment, Tauranga City

Technical Report Prepared for Tauranga City Council

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Executive Summary

Peak ground accelerations (PGA) for seismic design of liquefaction and landslide / slope instability are computed for the Tauranga city area. The PGA values vary spatially as a result of different geotechnical conditions, and are provided as spatial maps and tabulated data for GIS plotting. The spatial mapping is enabled through the use of a regional model of Vs30 – which provides a continuous variation in site conditions, in contrast to discrete site classes.

The sections to follow present firstly the modelling of the soil conditions over the city area through the use of a regional Vs30 model (Section 1). Secondly, the seismic hazard results are conveyed in the context of a generic site in central Tauranga to illustrate the variation with exceedance probability and also soil conditions (Section 2). Through a combination of the seismic hazard and spatially-varying soil conditions, regional PGA hazard maps are then obtained (Section 3), and the format of the output is briefly mentioned to enable 3rd-party display of the information in a geographical setting.

1. Regional variation in seismic site conditions

Geotechnical conditions vary over short distances, and can be classified in detail using geotechnical site investigations for the purpose of liquefaction estimation and foundation design. For the purpose of seismic hazard analysis, the principal parameter of interest is the 30-m averaged shear wave velocity, Vs30, which varies less significantly than shallow geotechnical conditions, and can be obtained from regional Vs30 models for use in region-wide applications.

It is noted that Vs30 provides a continuous representation in the variation of soil conditions for the purpose of seismic hazard analysis calculations, and therefore is preferred over the use of discrete site classifications – such as that used in NZS1170.5, for example. Abrahamson et al. (2008), for example, provide discussion on the treatment of soil conditions through the use of Vs30 within a range of different empirical ground motion models.

For the Tauranga City area, the model of Foster et al. (2019), as shown in Figure 1, was used to estimate the Vs30 values – which range from approximately 180-600m/s. This regional Vs30 model is based on a combination of surficial geology, topographic terrain, and geotechnical and geophysical measurements. Because it is a regional model, it is not a direct substitute for a site-specific geotechnical assessment. As a consequence, the results presented based on this model are useful in the consideration of regional seismic hazard triaging, for example, urban development (e.g. housing and horizontal infrastructure). They are not appropriate for site-specific assessment of high-importance structures (e.g. multi-storey commercial or industry structures) in lieu of conventional prescriptive design standards and guidelines.

It is important to note that this model provides values only for areas of native land, that is, reclaimed land in the Port of Tauranga area is not included. The Vs30 values are lowest (180-220m/s) in low-lying regions that are particularly susceptible to liquefaction. Generally sites with Vs30>300m/s are unlikely to be susceptible to liquefaction.

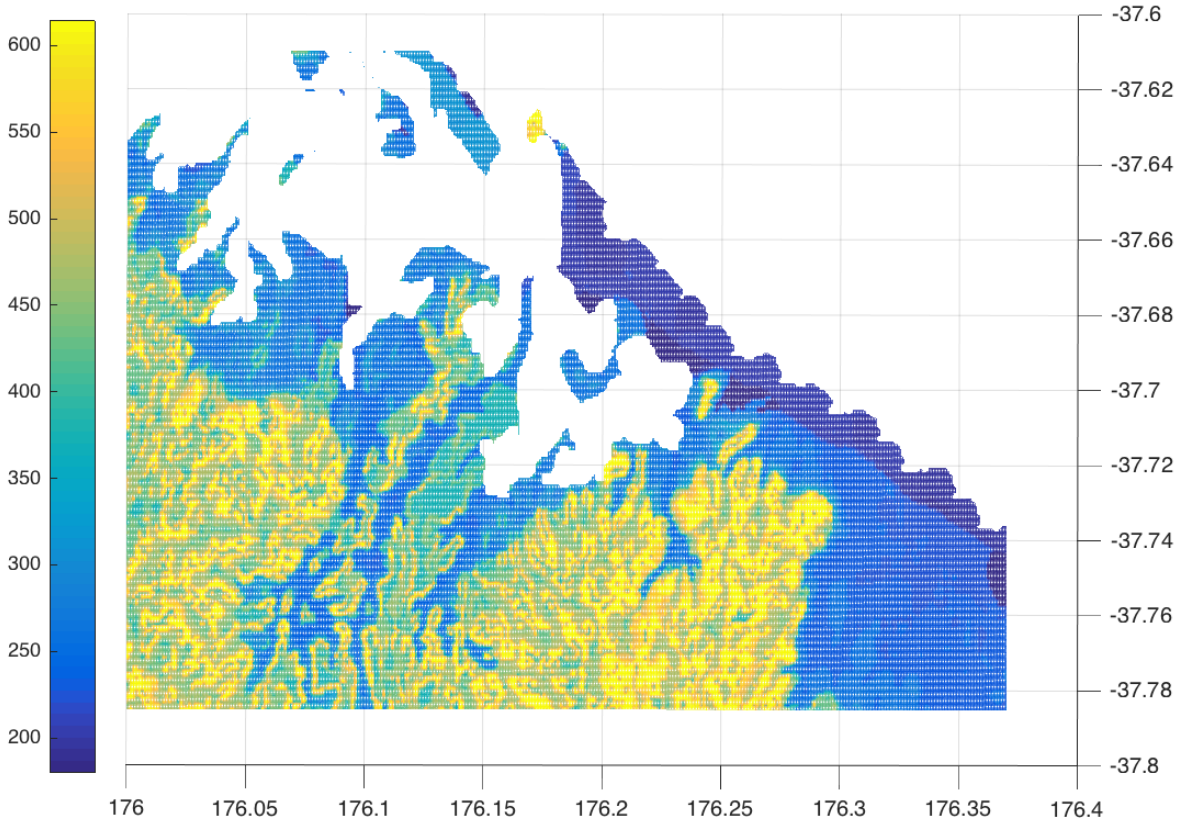


Figure 1: Variation in 30m shear wave velocity (Vs30) (colors in units of m/s) in the Tauranga city region. Latitude and Longitude in WGS84 units.

2. Seismic hazard for generic site in central Tauranga

A probabilistic seismic hazard analysis (PSHA) for a site in central Tauranga was computed to characterise the ground motion PGA hazard for the city area. Because of the small spatial extent of the city area, and that the hazard is dominated by distributed seismicity (as discussed below), the variation in seismic hazard due to geographical location in this area is small. The primary factor in the variation in the seismic hazard is the local soil conditions (as quantified via Vs30, presented in the previous section). As a result, the seismic hazard for a generic site in central Tauranga city is illustrated in this section to indicate the effect of soil conditions.

PSHA is based on an earthquake rupture forecast (ERF), defining the location, characteristics, and frequency of earthquakes, as well as ground motion prediction equations which predict the ground motion intensity for a given earthquake rupture. Kramer (1996) provides an introduction to PSHA. Computations were performed using the OpenSHA software (2005). Additional computational parameters are provided in Appendix A.

2.1. Earthquake rupture forecast (ERF)

The seismic hazard analyses performed utilize the model of Stirling et al. (2012), which was completed in mid-2010, and represents a national consensus model at that time. Figure 2 illustrates the mapped faults in the region.

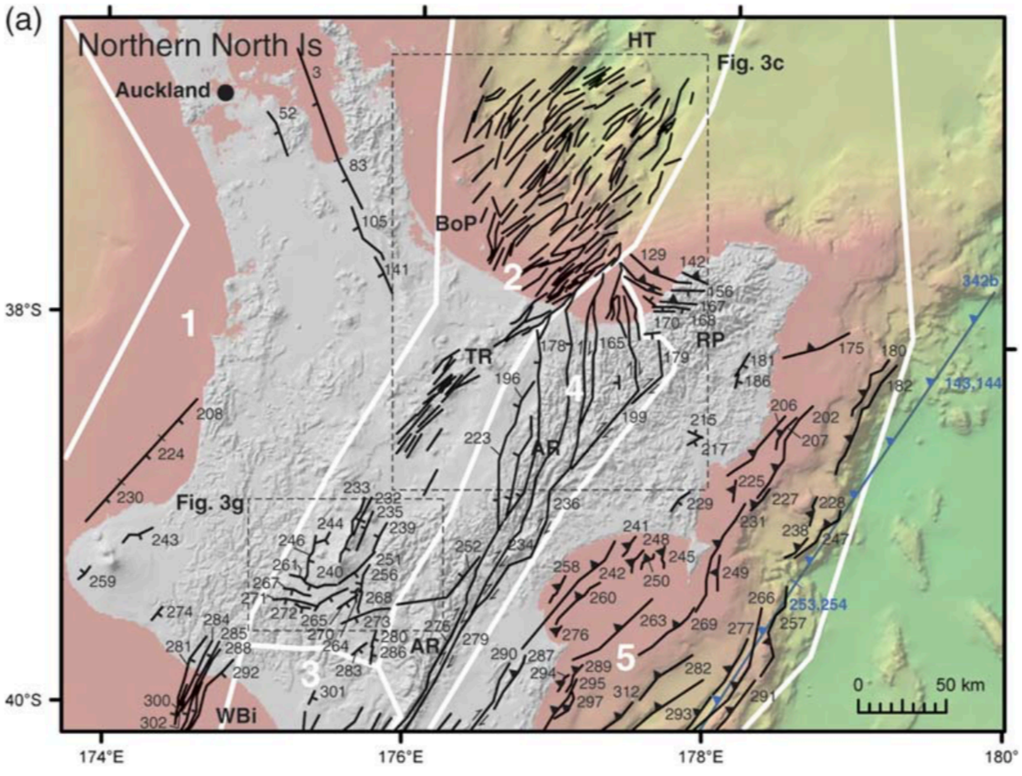


Figure 2: Mapped fault structures in the Northern North Island. The seismic hazard at the site is predominately affected by distributed seismicity as well as nearby faults in the offshore region.

Since the publication of Stirling et al. additional research has been documented on the Kerepehi fault system. Persaud et al. (2016) provide a recent summary of paleoseismic evidence of rupture on the Kerepehi fault system. It is noted that the field investigation data in this paper is the same data used in the national concensus model of Stirling et al. (2012) (Stirling et al. refer to ‘unpublished data’ – i.e. Persaud et al. is the resulting publication of this data). The primary difference is that Persaud et al. describe the fault system through the use of 7 different segments (based on surface expression), while Stirling et al. aggregate several segments in order to represent the system using 4 distinct rupture scenarios (which result in larger potential magnitude events – which is more important for seismic hazard calculations). The total length of faults in both cases is approximately 150km; and the average recurrence intervals, excluding the offshore segment, is approximately the same (6000 years). As a result, the use of the Kerepehi fault system modelling in Stirling et al. still represents best available science.

The Hikurangi subduction interface is the major seismic source in the upper North Island, however the subsequent hazard analyses illustrate that the distance of nearly 200km is such that it does not make an appreciable contribution to the seismic hazard at the site.

2.2. Ground motion prediction equations (GMPEs)

Two ground motion models were considered for seismic hazards resulting from shallow crustal and subduction earthquake sources. The NZ-specific Bradley (2013) model for shallow crustal earthquakes, and the Zhao et al. (2006) model was used for subduction zone sources, though the latter do not contribute any significant contribution to the seismic hazard at this site.

2.3. Seismic hazard results

Figure 3 illustrates the seismic hazard at the generic site for seven different values of Vs30, which encompass the range of values across the Tauranga city region. There is a general trend of higher hazard for lower values of Vs30 – i.e. the largest relative hazard occurs in softer soil sites (with lower Vs30 values).

For comparison, the dashed black and grey line illustrates the PGA hazard from NZS1170.5:2004 (Z=0.20) and the NZGS guidelines (NZGS, 2016), based on $C_{0,1000}$=0.34 for Tauranga and site class D soil conditions. The site-specific hazard and code/guideline-based hazard are similar for smaller return periods, but the code/guideline-based hazard is conservative for the larger return periods. Further explanation for these differences is provided in Section 2.4.

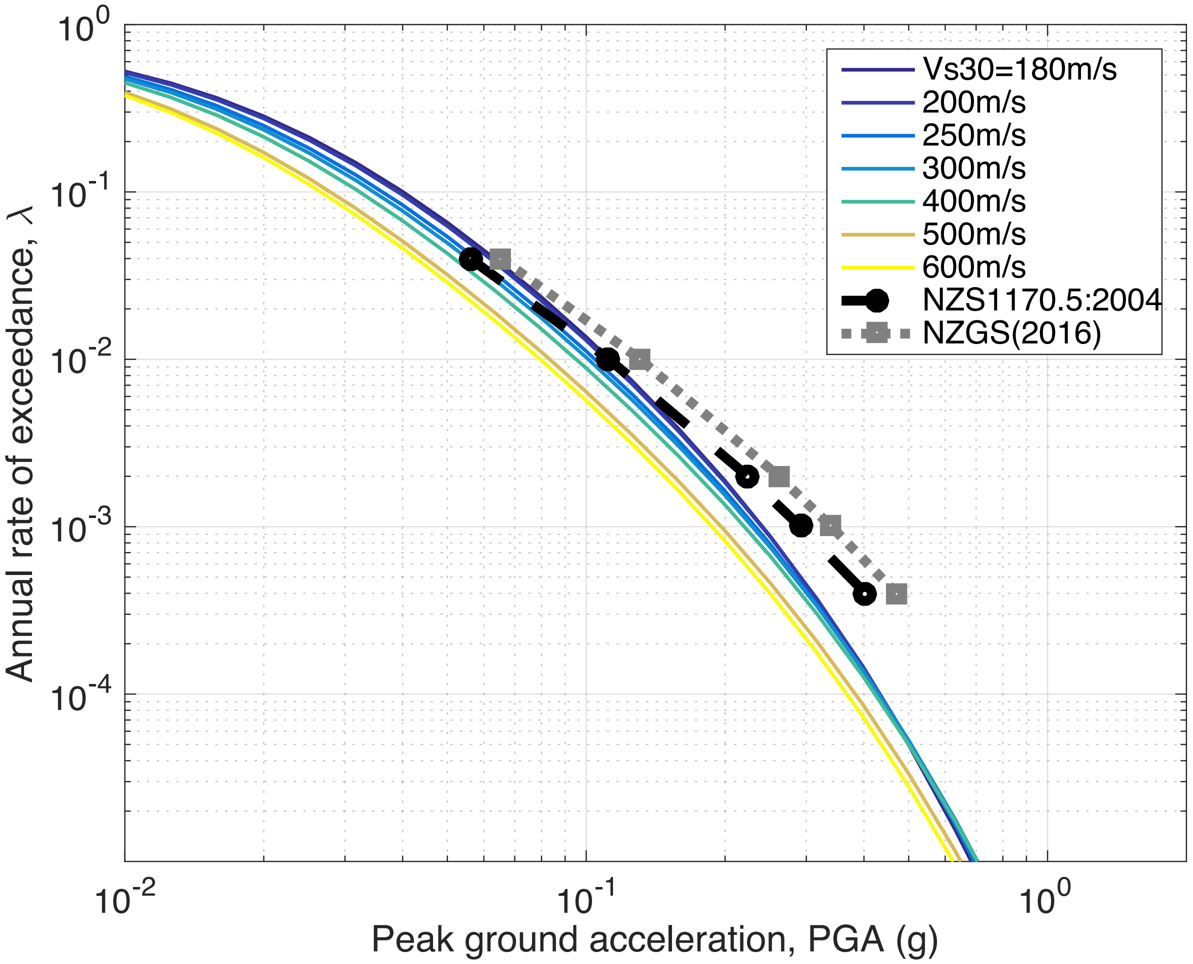


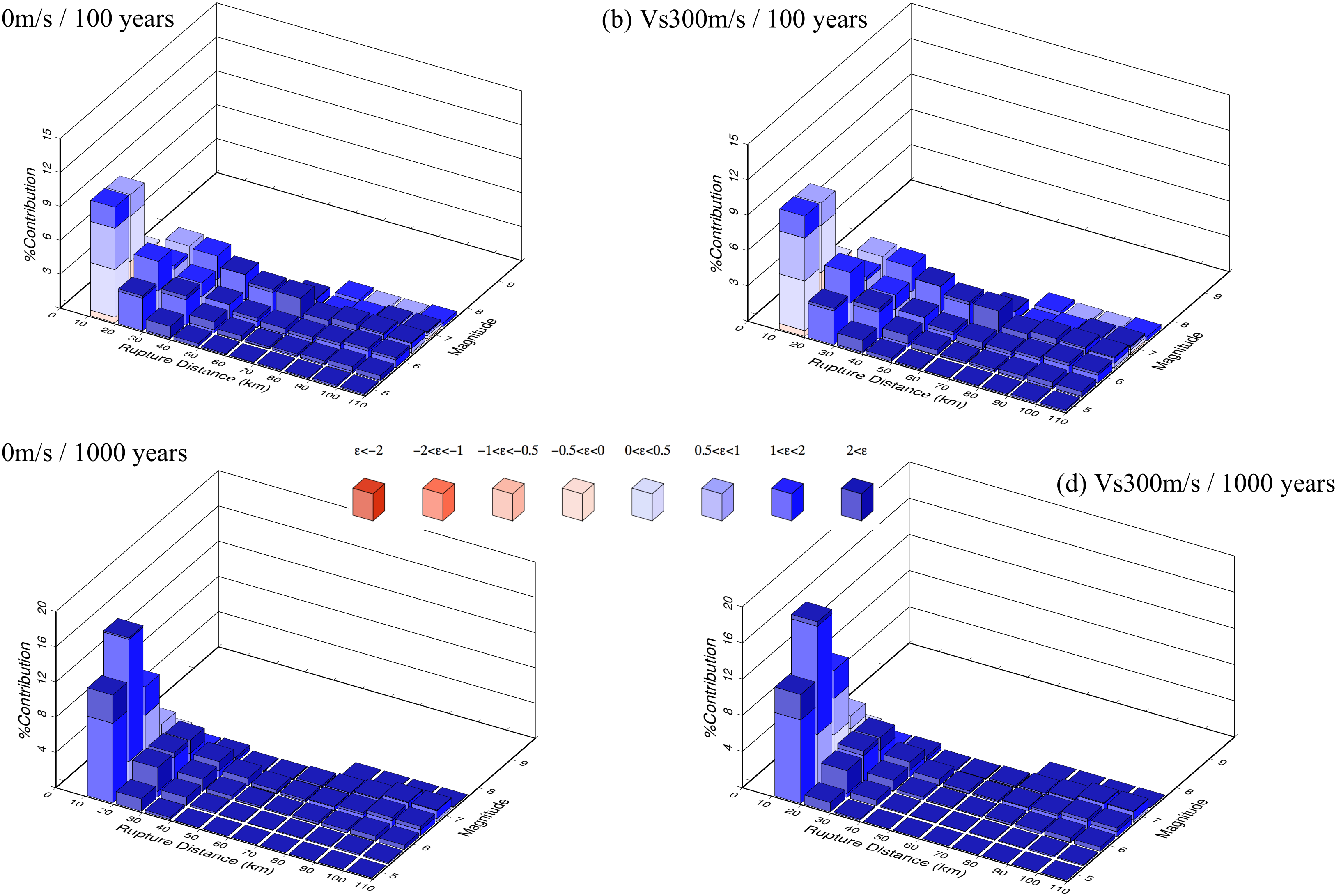
Figure 3: Seismic hazard curves for peak ground acceleration illustrating the effect of soil conditions as quantified through Vs30. The code and guideline-based hazard curves from NZS1170.5 and NZGS (2016) are also provided for reference.

Figure 4 illustrates the seismic hazard disaggregation results – which simply represent the fractional contribution of different seismic sources to the aggregate seismic hazard (i.e. Figure 3). Figure 4 illustrates that the hazard is dominated by nearby distributed seismicity (accounting for unmapped faults), although approximately 10% of the hazard is contributed by earthquakes on the distant Hikurangi subduction zone.

For use in geohazard analyses (liquefaction and landslide) the mean magnitude is often useful. The mean magnitude ranges from 6.1-6.3 across the different cases considered. It is practically independent of site conditions (Vs30), but does vary in a predictable manner with return period. For the 100 year return period the mean magnitude is 6.1; while for the 1000 year return period it is 6.3 (and similarly for the 3030 year return period).

Table 1: Mean magnitude with return period

Return period	25	100	500	1000	3030
Mean magnitude	6.1	6.1	6.2	6.3	6.3



(a) Vs180m/s / 100 years

(b) Vs300m/s / 100 years

(c) Vs180m/s / 1000 years

(d) Vs300m/s / 1000 years

Figure 4: Disaggregation plots for seismic hazard analysis for different exceedance probabilities and soil conditions.

2.4. Reasons for differences between site-specific and NZGS/NZS1170.5 hazard

There are numerous reasons for the differences between the NZGS/NZS1170.5-based guideline/code and site-specific hazard results shown in this section, most notably:

1. The site-specific values presented here are ‘direct’ results obtained from probabilistic seismic hazard analyses, and not ‘codified’ values within a functional methodology adopted for design codes, which is intentionally conservative (McVerry 2003). This is illustrated, for example, by the different ‘shape’ of the site-specific hazard as a function of return period, relative to the code-based variation.
2. The NZS1170.5-based hazard (with Z=0.20), and NZGS (2016) (with $C_{0,1000}$=0.34) was derived based on science in 2002 (in preparation for the 2004 code document). This study uses up-to-date information on seismic sources (consensus models from 2012, that are still relevant to the present day, (Stirling et al., 2012)) and ground motion modelling which has been specifically developed for NZ conditions, and independently validated using recent earthquake observations in the Canterbury earthquake sequence (Bradley, 2013).
3. The difference between NZS1170.5 and NZGS is primarily the difference between magnitude weighted and unweighted PGA values.
4. The general reason for the conservatism in the NZGS (and NZS1170.5) values is that the McVerry et al. (2006) ground motion model used in the development of these standard/guideline numbers is known to appreciably over-estimate PGA amplitudes from small-to-moderate magnitude earthquakes, as explained in further detail by Bradley (2013). For this specific site, the earthquake sources are such that small-to-moderate magnitudes dominate the seismic hazard. The effect of this conservatism increases as the exceedance rate reduces for the same reason.

3. Spatial ground motion hazard for different return periods

Based on the PGA seismic hazard (i.e. Figure 3), and the site conditions over the region (i.e. Figure 1), maps of PGA over the region can be obtained. An example for the 1000 year return period is provided in Figure 5.

Digital files are also provided with [Lon,Lat,PGA] triplets to enable TCC to produce such spatial information in their desired format for the 25, 100, 500, 1000, and 3030 year return periods.

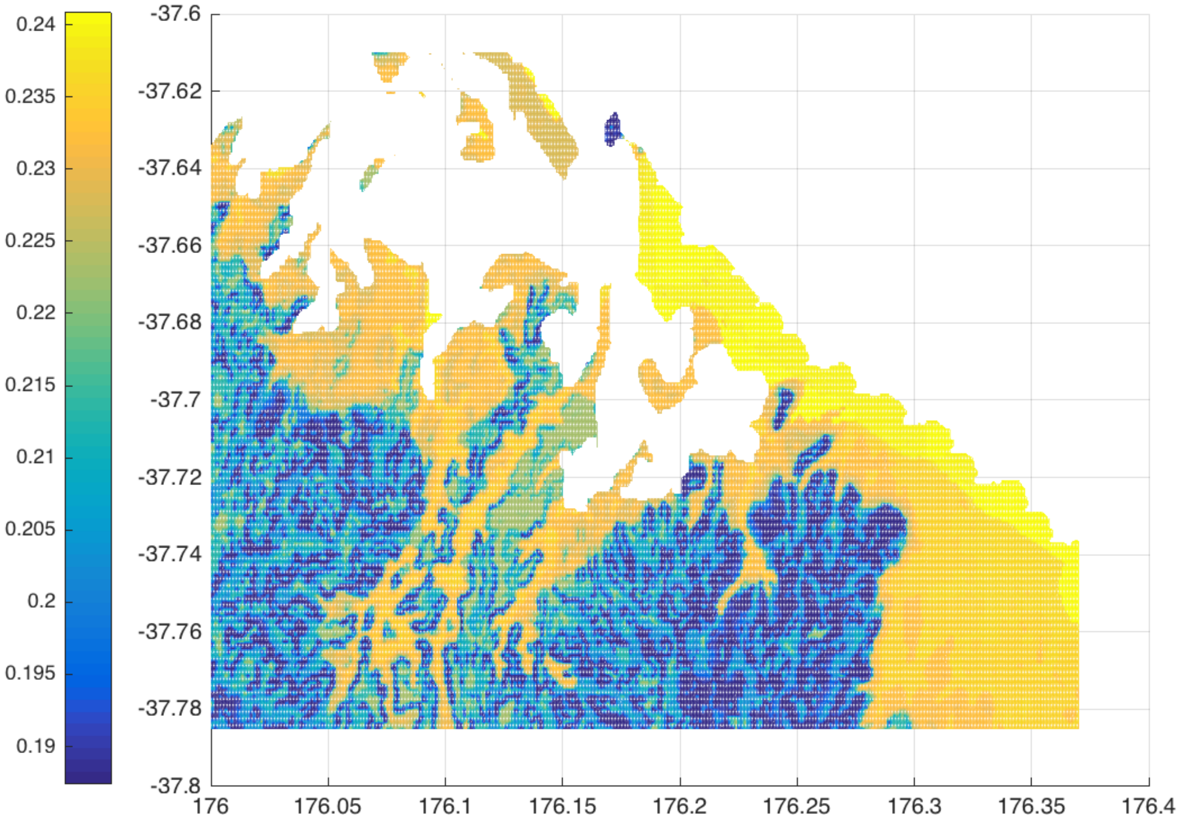


Figure 5: Example PGA hazard map for the 1000 year return period over the Tauranga City region

Example output file format:

```
Lon, Lat, PGA
 176.00000  -37.78500    0.163
 176.00040  -37.78500    0.162
 176.00050  -37.78500    0.159
 176.00060  -37.78500    0.157
 176.00070  -37.78500    0.154
```

4. Limitations and Application

The primary limitation in this work comes from the use of a regional Vs30 model, as opposed to using site-specific geotechnical and geophysical measurements. This regional Vs30 model is based on a combination of surficial geology, topographic terrain, and geotechnical and geophysical measurements. Because it is a regional model, it is not a direct substitute for a site-specific geotechnical assessment. As a consequence, the results presented based on this model are useful in the consideration of regional seismic hazard triaging, for example, urban development (e.g. housing and horizontal infrastructure). They are not considered appropriate as a substitute for a site-specific assessment of commercial or industrial structures in lieu of conventional prescriptive design standards and guidelines.

Because the results presented here are based on this regional Vs30 model then, where possible, specific geotechnical measurements should be used to confirm that the model assumptions are appropriate before adopting the consequent results. For example, regional geotechnical investigations for prospecting urban development will provide the means by which Vs30 values can be ascertained (e.g. if CPT information is obtained, as is typical, then the correlation of McGann et al. (2015) can be used to infer Vs values, and then the correlation of Boore et al. (2011) can be used to infer Vs30 if the CPT depth is less than 30m).

5. References

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