

Predicting Liquefaction in Near-Real-Time (NRT): An Assessment of Geospatial vs. Geotechnical Models During the Canterbury Earthquakes

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ABSTRACT

Semi-empirical models based on in-situ geotechnical tests have become the standard of practice for predicting soil liquefaction. Since the inception of the “simplified” cyclic-stress model in 1971, variants based on various in-situ tests have been developed, including the Cone Penetration Test (CPT). More recently, prediction models based solely on remotely-sensed data were developed. Similar to systems that provide automated content on earthquake impacts, these “geospatial” models aim to predict liquefaction for rapid response and loss estimation using readily-available data. This data includes (i) common ground-motion intensity measures (e.g., PGA), which can either be provided in near-real-time following an earthquake, or predicted for a future event; and (ii) geospatial parameters derived from digital elevation models, which are used to infer characteristics of the subsurface relevant to liquefaction. However, the predictive capabilities of geospatial and geotechnical models have not been directly compared, which could elucidate techniques for improving the geospatial models, and which would provide a baseline for measuring improvements. Accordingly, this study assesses the relative efficacy of liquefaction models based on geospatial vs. CPT data using 9,908 case-studies from the 2010-2016 Canterbury earthquakes. While the top-performing models are CPT-based, the geospatial models perform relatively well given their simplicity and low cost. Although further research is needed (e.g., to improve upon the performance of current models), the findings of this study suggest that geospatial models have the potential to provide valuable first-order predictions of liquefaction occurrence and consequence. Towards this end, performance assessments of geospatial vs. geotechnical models are ongoing for more than 20 additional global earthquakes.

DATA & METHODOLOGY

Performance is assessed using 9,908 case-studies compiled from three earthquakes (Table 1). The locations of these cases are mapped in Figure 1. The geotechnical aspects of this dataset are discussed in detail in [1,2].

Table 1. Case Studies Analyzed

Mo/Year	Earthquake	# Cases
Sept 2010	Darfield	3,647
Feb 2011	Christchurch	3,700
Feb 2016	Valentines Day	2,296
		9,908

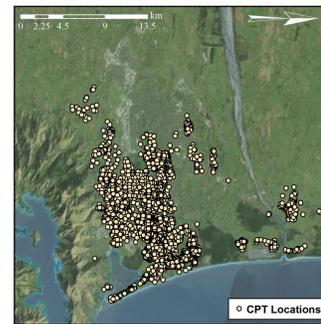


Figure 1. Case-study locations

Geotechnical Models

Liquefaction Potential Index, LPI [4], using triggering models of:
 1. Idriss & Boulanger (2008) [5]: (Geotechnical Model 1)
 2. Boulanger & Idriss (2014) [6]: (Geotechnical Model 2)

Geospatial Models

The models of Zhu et al. [7,8], computed from geospatial data as:

$$P(X) = (1 + e^{-X})^{-1}$$

- Global Geospatial Model 1 (Zhu et al., 2015) [7]:

$$X = 24.10 + 2.067 \cdot \ln(PGA_M) + 0.355 \cdot CTI - 0.4784 \cdot \ln(V_{s30})$$
- Global Geospatial Model 2 (Zhu et al., 2017) [8]:

$$X = 12.435 + 0.301 \cdot \ln(PGV) - 2.615 \cdot \ln(V_{s30}) + 5.556 \times 10^{-4} \cdot precip - 0.0287 \cdot (d_c)^{0.5} + 0.0666 \cdot d_r - 0.0369 \cdot d_r \cdot (d_c)^{0.5}$$
- Region-Specific Geospatial Model [7]:

$$X = 25.45 + 2.476 \cdot \ln(PGA_M) - 0.323 \cdot d_{r3} - 4.241 \cdot \ln(V_{s30})$$

Where: $P(X)$ = probability of surface manifestation; CTI = compound topographic index, PGA_M = magnitude-weighted PGA, V_{s30} = shear-wave velocity (cm/s) of the upper 30-m, estimated from topographic slope; d_r = distance to rivers (km); d_c = distance to coast (km); $precip$ = mean annual precipitation (mm)

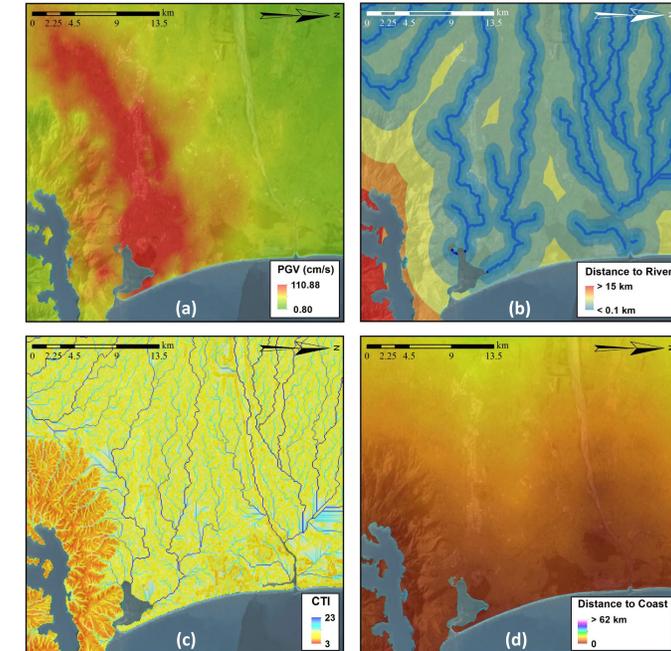


Figure 2. Select inputs to the geospatial models: (a) Peak Ground Velocity, PGV; (b) Distance to rivers; (c) Compound Topographic Index, CTI; and (d) Distance to Coast.

RESULTS

Model efficacy is assessed using receiver-operating-characteristic (ROC) analysis, which plots the True Positive Rate vs. the False Positive Rate as a function of index-test results. While no single parameter fully characterizes performance, the area under a ROC curve (AUC) is commonly used for this purpose and is the probability that “manifestation” cases have higher index-values than “no manifestation” cases. A larger AUC thus indicates better model performance.

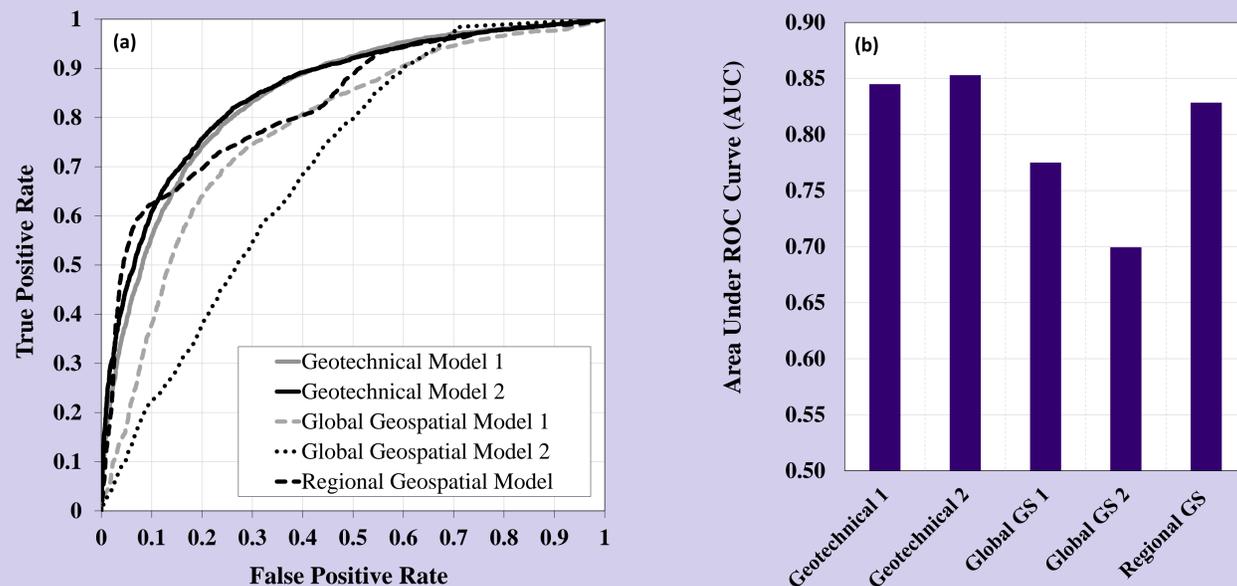


Figure 3. (a) Receiver operating characteristic (ROC) analysis of liquefaction prediction models based on geospatial vs. geotechnical data; (b) summary of model performance, as quantified by the area under the ROC curve (AUC).

KEY FINDINGS

The geotechnical and geospatial models were evaluated on their ability to predict whether sites had surface-manifestations of liquefaction, the results of which are summarized in Figure 3. The key findings are as follows:

- Of the five models evaluated, the two best-performing were Geotechnical Models 1 (AUC = 0.845) and 2 (AUC = 0.853).
- However, considering the simplicity and low cost of the geospatial models, their performance was relatively good.
- In particular, the region-specific geospatial model of Zhu et al. (2015) was nearly as efficacious (AUC = 0.828) as the geotechnical models.**
- In contrast, the global geospatial model of Zhu et al. (2017), with AUC = 0.70, was nearer to random guessing than to a perfect model.
- Notably, the Zhu et al. (2017) model is an update to the Zhu et al. (2015) model, the latter of which was more efficacious. This may be because the 2015 model was heavily influenced (i.e., biased) by data from the Canterbury earthquakes, whereas the updated model was developed using data from 27 events. Further research is needed to determine why the model-update performs worse for the cases studied herein.
- While there is significant room for improvement, the findings generally suggest that geospatial models have the potential to provide valuable first-order predictions of liquefaction occurrence and consequence.**

FUTURE WORK

Several thrusts of future investigation are as follows:

- Rigorous analyses of the Canterbury earthquakes, including assessment of: (1) why the Zhu et al. (2017) update performs worse for the evaluated cases; and (2) whether geospatial models perform better when site-specific data are incorporated (e.g., measured V_{s30}).
- Performance assessments of geospatial vs. geotechnical models in more than 20 additional earthquakes.
- Extending geospatial models to predict the downstream effects of liquefaction (e.g., the magnitude of ground deformation; the severity of damage to infrastructure; and economic impacts), which can be incorporated into simulations and NRT systems (e.g., USGS PAGER).

REFERENCES

- Maurer, B.W., Green, R.A., Cubrinovski, M., and Bradley, B. (2015). “Fines-content effects on liquefaction hazard evaluation for infrastructure in Christchurch, New Zealand.” *Soil Dynamics and Earthquake Engineering* 76: 58-68.
- Maurer, B.W., Green, R.A., Cubrinovski, M., and Bradley, B. (2014). “Evaluation of the liquefaction potential index for assessing liquefaction hazard in Christchurch, New Zealand.” *Journal of Geotechnical and Geoenvironmental Engineering* 140(7), 04014032.
- Green, R.A., Cubrinovski, M., Cox, B., Wood, C., Wotherspoon, L., Bradley, B., & Maurer, B.W. (2014). “Select Liquefaction Case Histories from the 2010-2011 Canterbury Earthquake Sequence.” *Earthquake Spectra*, 30(1): 131-153.
- Iwasaki, T., Tatsuoka, F., Tokida, K., & Yasuda, S. (1978). “A practical method for assessing soil liquefaction potential based on case studies at various sites in Japan.” *2nd Intl Conference on Microzonation*, Nov 26-Dec 1, San Francisco, USA.
- Idriss, I.M. & Boulanger, R.W. (2008). “Soil liquefaction during earthquakes.” *Monograph MNO-12*, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.
- Boulanger, R.W. and Idriss, I.M. (2014). “CPT and SPT based liquefaction triggering procedures.” *Report No. UCD/CGM-14/01*, UC Davis, CA, USA.
- Zhu, J., Daley, D., Baise, L.G., Thompson, E.M., Wald, D.J., and Knudsen, K.L. (2014). “A geospatial liquefaction model for rapid response and loss estimation.” *Earthquake Spectra* 31(3): 1813-1837.
- Zhu, J., Baise, L.G., Thompson, E.M. (2017). “An updated geospatial liquefaction model for global application.” *Bulletin of the Seismological Society of America* 107(3): doi: 10.1785/0120160198