Sensitivity of predicted liquefaction-induced lateral displacements from the 2010 Darfield and 2011 Christchurch Earthquakes

Kelly Robinson, Misko Cubrinovski, Brendon A. Bradley
Department of Civil and Natural Resource Engineering, University of Canterbury
kelly.robinson@pg.canterbury.ac.nz

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Introduction

Liquefaction-induced lateral spreading in Christchurch and surrounding suburbs during the recent Canterbury Earthquake Sequence (2010-2011) caused significant damage to structures and lifelines located in close proximity to streams and rivers. Simplified methods used in current engineering practice for predicting lateral ground displacements exhibit a high degree of epistemic uncertainty, but provide 'order of magnitude' estimates to appraise the hazard. We wish to compare model predictions to field measurements in order to assess the model's capabilities and limitations with respect to Christchurch conditions.

The analysis presented focuses on the widely-used empirical model of Youd et al. (2002), developed based on multi-linear regression (MLR) of case history data from lateral spreading occurrence in Japan and the US. Two issues arising from the application of this model to Christchurch were considered:

- Small data set of Standard Penetration Test (SPT) and soil gradation indices (fines content *FC*, and mean grain size, D_{50}) required for input. We attempt to use widely available CPT data with site specific correlations to *FC* and D_{50}.
- Uncertainty associated with the model input parameters and their influence on predicted displacements. This has been investigated for a specific location through a sensitivity analysis.

The Youd et al. (2002) model MLR equation:

$$\log D_h = -16.713+1.532\, M_w - 1.406R^* - 0.012R+0.592 \log W+0.540 \log T_{15} + 3.413 \log (100 - F_{15}) - 0.795 \log (D50_{15} + 0.1mm)$$

where D_H - lateral spreading displacement (m); Mw - EQ moment magnitude;
R - horizontal distance to nearest seismic source or fault rupture (km);
$R^*=R+R_0$ is the modified source distance ($R_0=10^{(0.89Mw-5.64)}$);
$W=H/L*100$ - free-face ratio (H=height of free-face, L=distance from crest of free-face);
T_{15} - thickness (m) of saturated, cohesionless sediment with $SPT\ (N1)_{60}<15$;
F_{15} - average fines content within T_{15};
$D50_{15}$ - median grain size (mm) within T_{15}.

Case Study

Lateral ground displacements measured along the Avon Loop, situated in the north-east of the Central Business District in Christchurch, ranged from < 10cm to ~1.6m following the 22 Feb Earthquake (Robinson et al. 2012, Robinson et al. 2011).

- Method of ground surveying
- Record crack dimensions and distance from waterway along transect
- Transects are oriented perpendicular to bank
- Maximum displacement = sum of crack widths along transect (max at water's edge)

The transects where spreading displacements were measured, and nearby CPT locations are shown in Figure 1. It is noted that no field data was collected following the 4 September 2010 event and the measurements shown are assumed to be cumulative.

In addition to the data within the Avon Loop, a large amount of CPT and SPT data from sites along the Avon River (<300m) provided by CERA (2012) (Fig 2) were collated in order to establish relationships for determining the Youd model parameters F_{15} and $D50_{15}$ from CPT data (Figure 2).

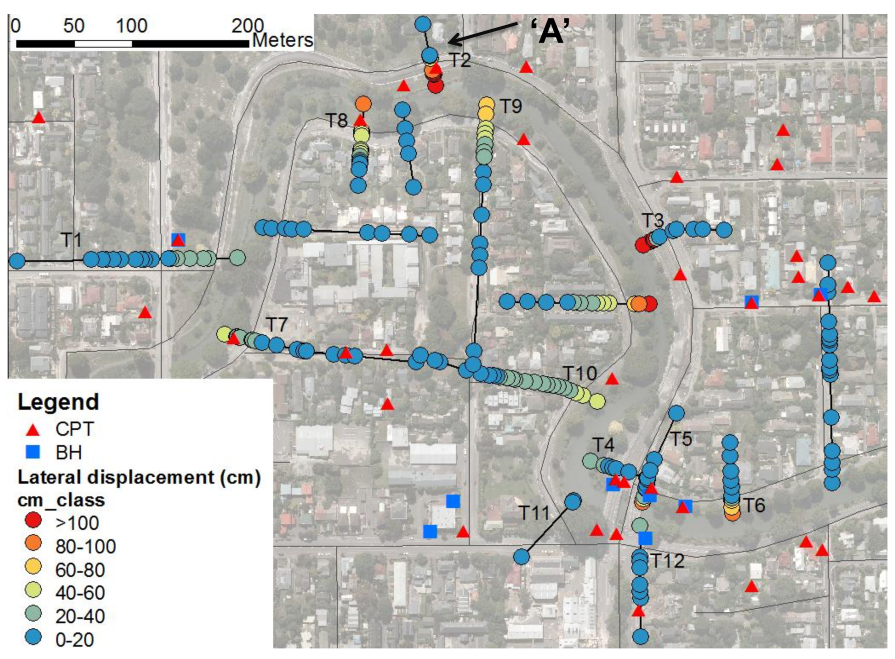

Figure 1. Lateral spreading field measurements in the Avon Loop following 22 Feb EQ

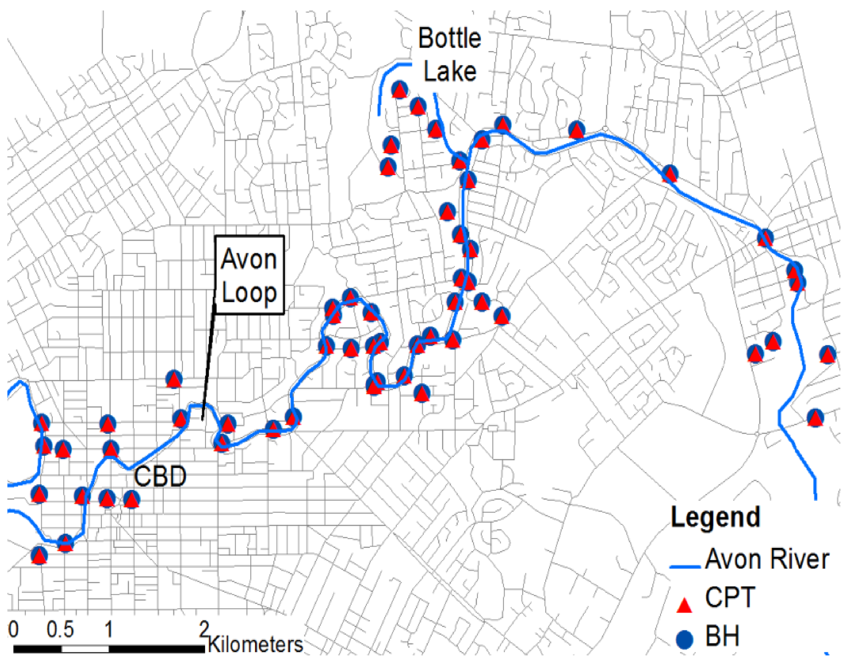

Figure 2. Location plan of subsurface explorations used in analysis

Collated Data

SPT grain size data located within 5m of the CPT were used in the analysis. Average I_c-values (after Youd et al. 2001) were estimated at the corresponding depths of soil gradation data in adjacent boreholes.

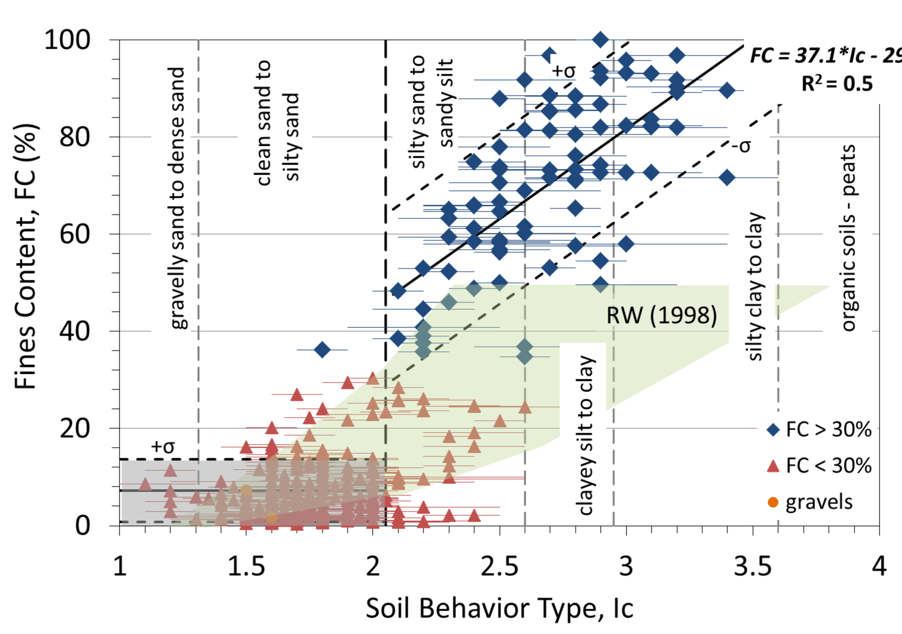

Figure 3. Correlation between I_c and *FC* for Christchurch soils and comparison with Robertson and Wride (1998)

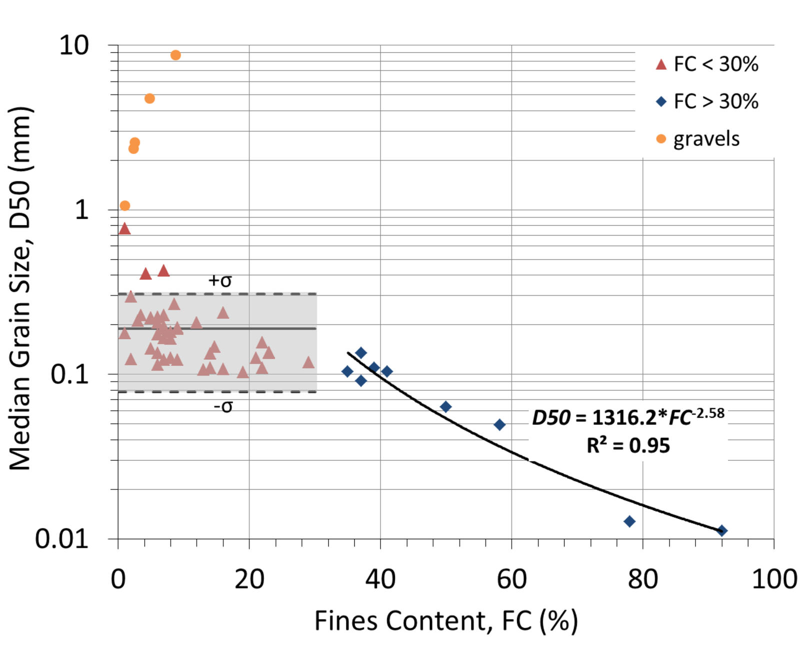

Figure 4. Relationship for Christchurch soils between *D50* and *FC*

Findings from Collated Data

- We establish correlation between I_c-*FC* for *FC* > 30% corresponding to I_c–values > 2.05 (equivalent to the Robertson and Wride (1998) soil type behaviour boundary between clean sand to silty sand and silty sand to sandy silt – Figure 3).
- The data (*FC* > 30%) generally fits with the lower bound presented in Robertson and Wride (1998) for low-plasticity soils (*PI* < 5%), as expected given the non-plastic nature of the fluvial silty sands prevalent in Christchurch.
- For I_c < 2.05, the majority of data (+/- sigma) range between *FC*~0-14% with an average *FC* ~7%.
- We establish generally good correlation between *FC-D50* for *FC* > 30% – Fig. 4.
- For *FC* < 30%, Figure 4 provides a definitive range of *D50* approximately between 0.08-0.31mm; with an average value of ~0.19mm.

Comparison of Field Observations and Youd Model Predictions

Model inputs were established as follows:

- *H* – determined from 2010 LiDAR survey (CERA 2012)
- *L* – distance from CPT to river estimated from aerial photo in GIS
- T_{15} – defined for CPT data as qc1<8MPa, below GW table, I_c<2.6
- F_{15} – use correlation for *FC>30%* when I_c*>2.05*, use average *FC=7%* for I_c < 2.05;
- $D50_{15}$ – if F_{15}*>30%*, estimate using correlation shown in Figure 4; if F_{15}*<30%*, use average value *D50=0.19mm*
- *R* and *PGA* – obtained from Bradley & Hughes (2012); *PGA* used to back-calculate *R* as alternative analysis using *Req*

Account for uncertainty in field measurements:

- Consider measured displacement within +/-10m of *'L'*
- Represented by horizontal error bars in Fig 5.

Account for uncertainty in CPT-based correlations:

- Determine upper and lower bounds for F_{15} from I_c using +/-σ (from Fig. 3)
- Compute $D50_{15}$ for the appropriate F_{15} boundary (based on Fig. 4 correlations) and incorporate in analysis
- Represented by vertical error bars in Fig. 5
- Uncertainty in *D50-FC* relationship for F_{15}*<30%* addressed in sensitivity analysis

The analysis was performed for each of the two events and the results summed to show the total empirical prediction plotted in Figure 5.

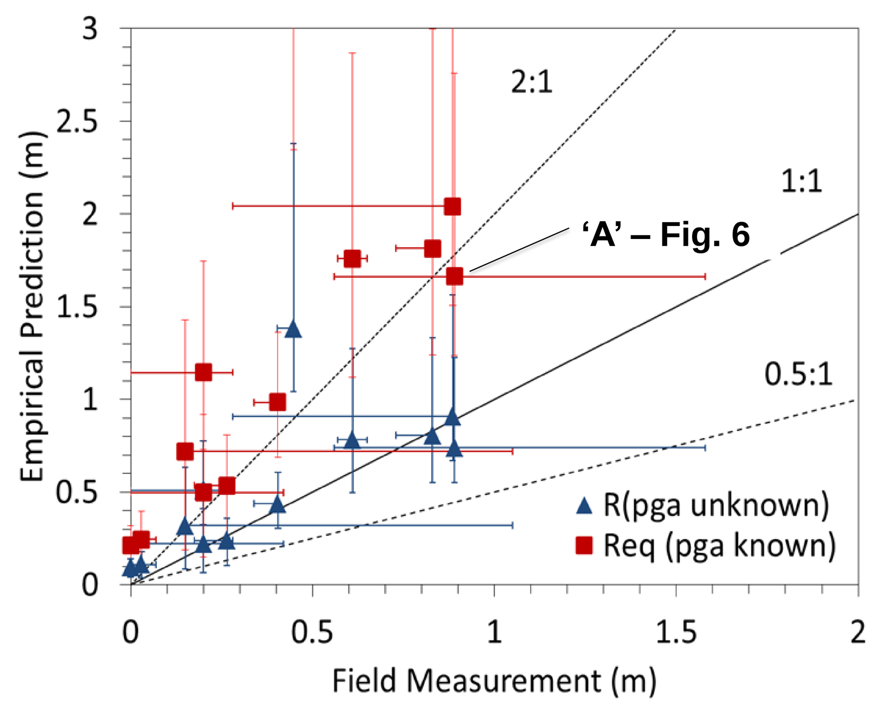

Figure 5. Comparison of field measurements in the Avon Loop with Youd model predictions

Sensitivity Analysis:

- Examine influence of uncertainties associated with the model inputs
- Consider specific location 'A' (Fig 1)
  - Field measurement of ~0.9m and model prediction of ~1.7m, using *Req* (Fig5)
- Vary input parameters with respect to associated uncertainty of each (Fig 6)

Figure 6 shows the model extremely sensitive to the ranges investigated.

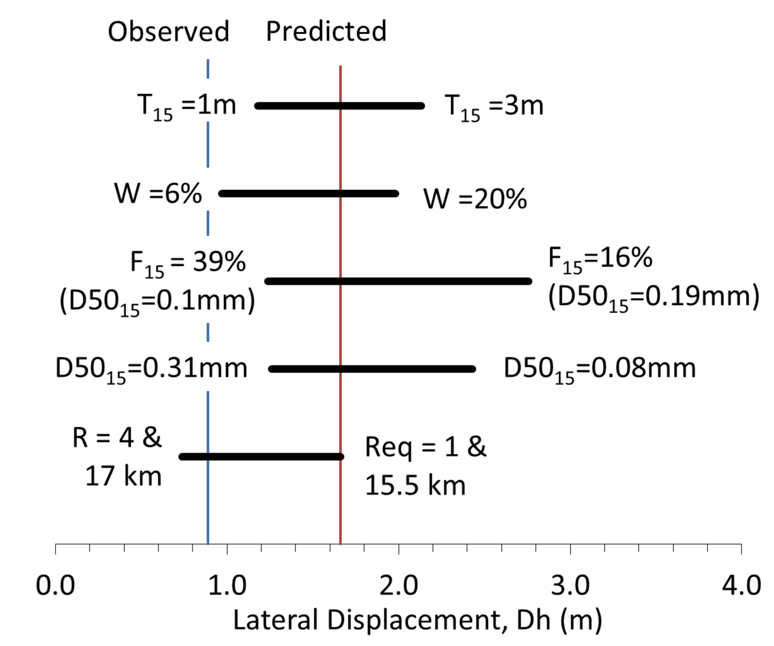

Figure 6. Sensitivity analysis of parameter uncertainties at location 'A'

Conclusions

Lateral spreading displacement measurements from the Christchurch earthquakes were compared to the empirical model of Youd et al. (2002). An attempt was made to derive the geotechnical parameters, *F15* and $D50_{15,}$ from CPT data.

- **Results in Figure 5 suggests agreement between the field and predicted values for the case considering *R* (PGA unknown) while the cases using *Req* tend to over-predict the field measurements.**
- **A sensitivity analysis was performed for a specific location and found the model to be highly sensitive to all input parameters. The strong influences of *F15* and $D50_{15}$ on the predictions indicate that the uncertainties associated with the derived correlations may be too significant for accurate application of the model.**

Future work on additional comparisons with the Youd model and others is on-going with an aim to achieve a more accurate method of lateral spreading predictions in Christchurch.

Acknowledgments

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References

Youd, LT, Hansen, CM, and Bartlett, SF. (2002). "Revised multilinear regression equations for prediction of lateral spread displacement." *Journal of Geotechnical and Geoenvironmental Engineering, 128(12), 1007-1017.*