### 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, D₅₀) required for input. We attempt to use widely available CPT data with site-specific correlations to FC and D₅₀.
- 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:

\[
\log D_{ls} = -16.713 + 1.532 \log M_{st} - 1.406 R + 0.012 R \times 0.592 \log W + 0.540 \log T_{gs} + 3.413 \log (100 - F_{wi}) - 0.795 \log (DSO_{50}, + 0.1 \mathrm{mm})
\]

where \(D_{ls}\) - lateral spreading displacement (mm); \(M_{st}\) - EQC moment magnitude; \(R\) - horizontal distance to nearest seismic source or fault rupture (km); \(R^* = R \times \exp(-0.064\log R)\); \(W = H/E^{0.3}H\) - free-face ratio (H=height of free-face, L=distance from crest of free-face); \(T_{gs}\) - thickness (m) of saturated, cohesionless sediment with SPT (N₁₅₀)\(<15\); \(F_{wi}\) - average fines content within \(T_{gs}\); \(DSO_{50}, \) - median grain size (mm) within \(T_{gs}\).

### Case Study

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

- 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 \(F_{wi}\) and \(DSO_{50}\) from CPT data (Figure 2).

### Collated Data

SPT grain size data located within 5m of the CPT were used in the analysis. Average \(I_{s}\) values (after Youd et al. 2001) were estimated at the corresponding depths of soil gradation data in adjacent bores.

### Findings from Collated Data

- We establish correlation between \(I_{s} FC\) for FC > 30% corresponding to \(I_{s}\) 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 \(I_{s} FC\) for 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-porous nature of the fluvial silty sands prevalent in Christchurch.
- For \(I_{s} > 2.05\), the majority of data (\(\sigma_{\mu}\) - sigma) range between FC-0.14% with an average FC ~7%.
- We establish generally good correlation between FC-DSO for FC > 30% – Fig. 4.
- For FC < 30%, Figure 4 provides a definitive range of DSO 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
- \(T_{gs}\) – defined for CPT data as q<15MPa, below GW table, and \(L<2.6\)
- \(F_{wi}\) – use correlation for FC>30% when \(I_{s}\geq2.05\), use average FC~7% for \(I_{s} < 2.05\).
- \(DSO_{50}\) – if \(F_{wi} > 30\%\), estimate using correlation shown in Figure 4, \(F_{wi} > 30\%\), use average value \(DSO_{50}=1.90\text{mm}\)
- \(R\) 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 dispersion prediction within +/-30mm of \(L^*\)
- Represented by horizontal error bars in Fig. 5

Account for uncertainty in CPT-based correlations:

- Determine upper and lower bounds for \(F_{wi}\) from \(I_{s}\) using \(<6\) from Fig. 3
- Compute \(DSO_{50}\) for the appropriate \(F_{wi}\) boundary (based on Fig. 4 correlations) and incorporate in analysis
- Represented by vertical error bars in Fig. 5
- Uncertainty in DSO-FC relationship for \(F_{wi}<30\%\) 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.

### Sensitivity Analysis

- Examine influence of uncertainties associated with the model inputs
- Consider specific location ‘A’ (Fig 1)
- Field measurement of <1.9m and model prediction of ~1.7m, using Req (Fig 5)
- Vary input parameters with respect to associated uncertainty of each (Fig 6)

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

### 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, \(F_{wi}\) and \(DSO_{50}\), 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 \(F_{wi}\) and \(DSO_{50}\) 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

The authors would like to acknowledge the New Zealand Earthquake Commission (EQC) for their continued financial support for this research.

### References