Te Hiranga Rū | QuakeCoRE
Aotearoa New Zealand Centre for Earthquake Resilience

Assessment of the liquefaction potential of loess soils, Banks Peninsula

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With support from a QuakeCoRE Proposal Development grant

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Overview:

1. What is loess?
2. Previous work … unsaturated soil behaviour!
3. Does loess liquefy?
4. Research plan

What is loess?

- Covers 10% South Island of New Zealand
- Holocene – Late Pleistocene age
- aeolian (windblown) deposit: several depositional episodes coinciding with glacial retreat
- Overlies Miocene age volcanics in Banks Peninsula

- Fine grained (60 – 75% silt)
- 3 - 45 % clay sized grains
- Low plasticity (4 < PI < 12)

- Generally unsaturated (!)

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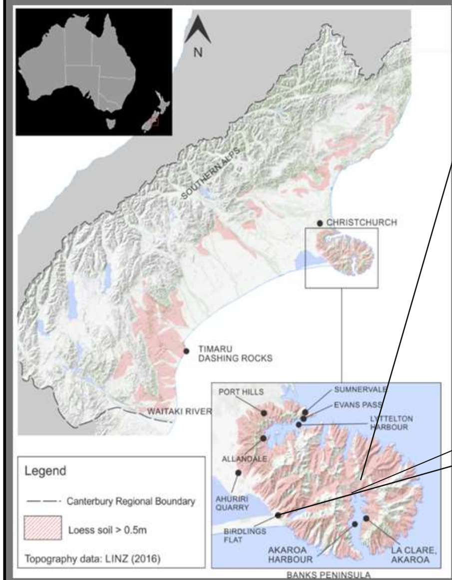
My PhD: An investigation of the soil-water characteristics and unsaturated shear strength behaviour of Akaroa loess

Supervisors: Prof Adrian Russell (UNSW), Dr Clark Fenton (UC)



Yates *et al.* (2018), *Engineering Geology*

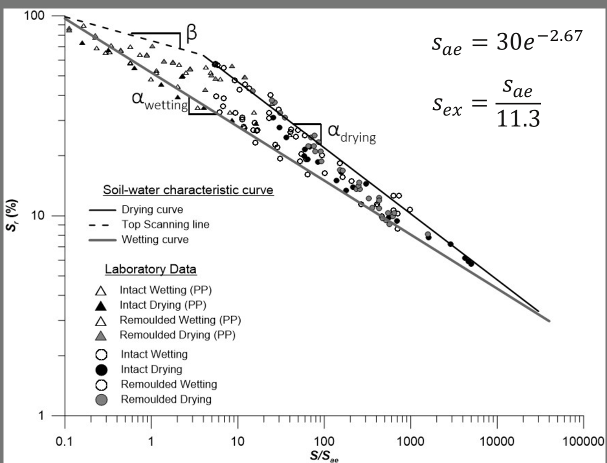
Shallow failure in road cutting, SH75, Akaroa Harbour

Near vertical ~20 m cut in intact loess (*w* <5%)

Earthflow failure, Duvauchelle, Akaroa Harbour

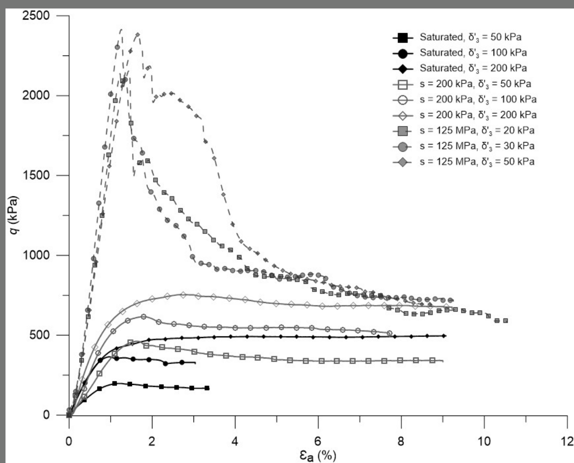
Laboratory Testing (UNSW)

Soil Water Characteristic Curve (SWCC) for intact and remoulded loess:



Yates & Russell (2022), *Geotechnique*

Unsaturated and saturated triaxial testing for intact and remoulded loess:



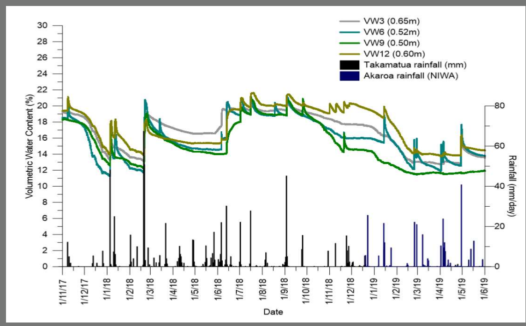
Unsaturated Triaxial testing: intact loess stress-strain plot

Additional laboratory testing:

- Mercury Porosimetry (intrusion & extrusion)
- Scanning Electron Microscopy
- Oedometer (standard)
- Carbonate content, Index properties, PSD etc.

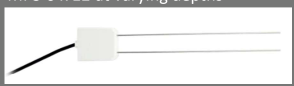
Long Term Field Instrumentation (Takamatua)

Field instrumentation site: Takamatua



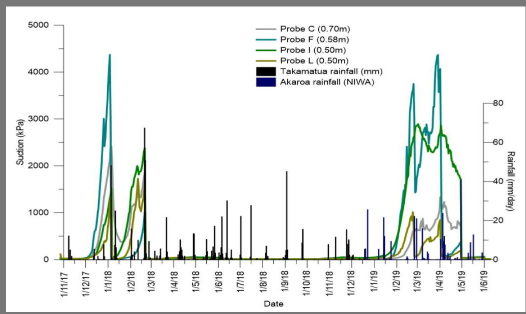
Yates & Russell (2022), *Geotechnique*

MPS-6 x 12 at varying depths



CS616 x 12 at varying depths

Rain gauge

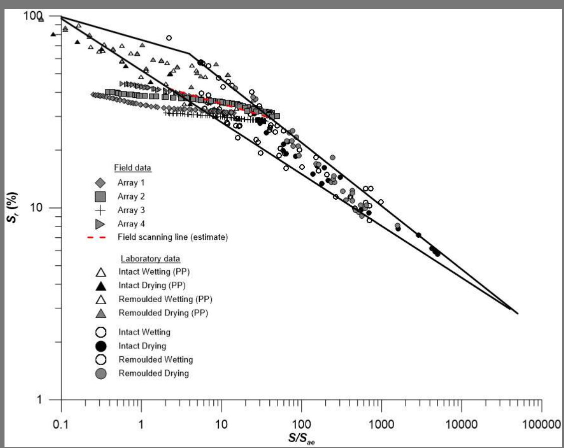


Yates & Russell (2022), *Geotechnique*

Comparing field & laboratory data:

Bishop (1959): $\tau = c' + ((\sigma - u_a) + \chi(u_a - u_w))\tan\phi'$

Overlay of field drying data (Summer 2019) on SWCC

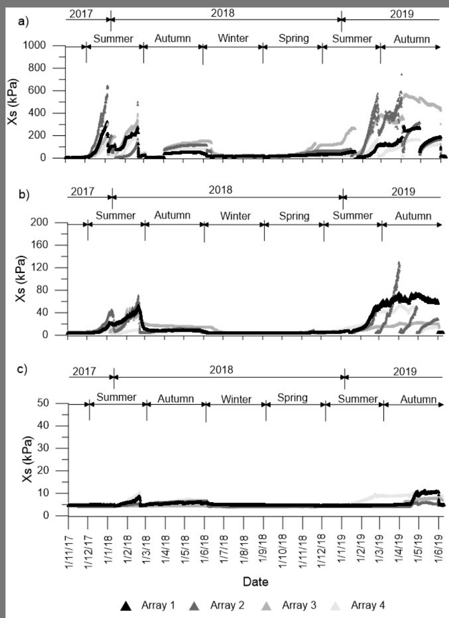


Yates & Russell (2022), *Geotechnique*

Key contributions

- In field conditions, wetting and drying of the loess causes the hydraulic state to remain on a scanning curve
- Using the field scanning line, field VWC data was used to calculate suction - comparison between calculated and measured suction values (right plot) is good. This validates treatment of loess as a fractal soil

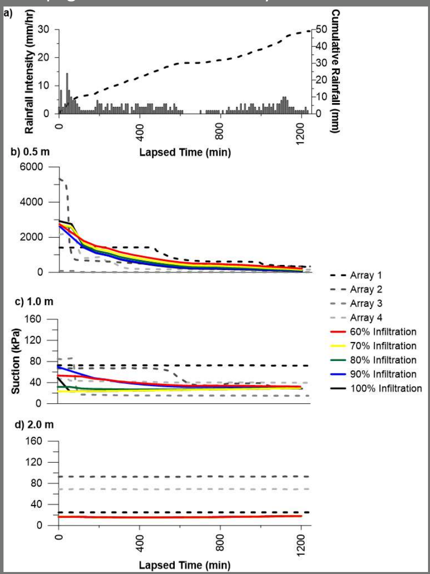
Temporal change in χs with seasonal changes



Yates & Russell (2022), *Geotechnique*

Numerical modelling (seepage & slope stability)

Seepage model for 5th January rainfall event

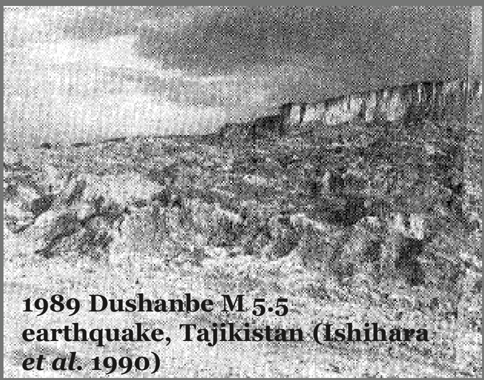


Ground truthing of slope models:

Key contributions

- Results from seepage analysis were comparable to moisture changes observed on site. This validated the calculated hydraulic conductivity function and SWCC.
- Simplified slope stability analysis (incorporating the changes in χs observed on site) showed the role of suction and microstructure in slope stability. This highlights the importance of understanding the seasonal moisture regime at a site for design optimisation.
- Demonstrated the use of the derived unsaturated parameters in seepage and stability analysis in a New Zealand soil context for engineering practice.

Ongoing loess work: Does loess liquefy?



Loess behaviour during earthquakes - what we know:

Internationally:

Field observations:

- 1920 Haiyuan M 8.5 earthquake, China (Wang *et al. 2014;* Pei *et al.* 2017)
- 1989 Dushanbe M 5.5 earthquake, Tajikistan (Ishihara *et al.* 1990)

Laboratory testing:

- Undrained cyclic triaxial tests on intact and remoulded loess to develop liquefaction (CSR-Nc) curves – mainly in China, also France, Bulgaria and USA
- SEM analysis - microstructural

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2010-2011 CES Maffey's Rd slope failure (Carey *et al.* 2017)

Loess behaviour during earthquakes - what we know:

New Zealand context:

Field observations:

- 2010 – 2011 Christchurch Earthquake Sequence – failures in loess slopes

Laboratory tests:

- Dynamic Shear Box testing of intact and remoulded loess from Maffeys Rd slope failure (Carey *et al.* 2017)
- Liquefaction was observed in some of the tests on intact loess. This study indicated that liquefaction is indeed a plausible mechanism contributing to slope failure in the low angle toe slopes where a **permanent ground water table** is present.

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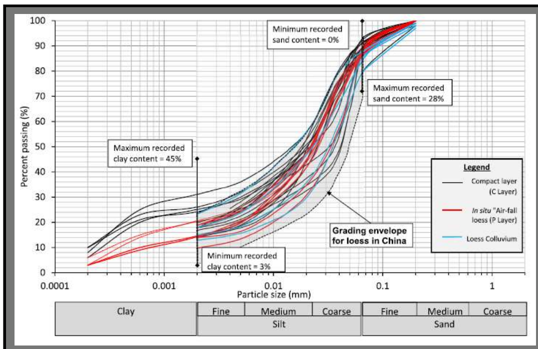
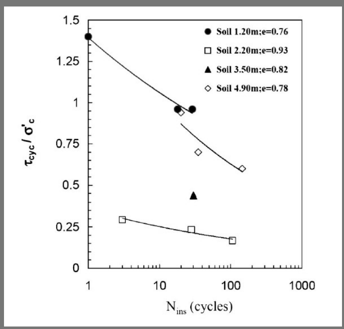


Loess particle size distribution (Yates *et al.* 2018)



Cyclic resistance of loess – Northern France (Karam *et al.* 2009)

Current understanding:

- Given PI < 12, according to Bray & Sancio (2006), when *wc*/LL > 0.85 liquefaction could occur
- International studies show that loess can liquefy HOWEVER this information can not be directly transferred to NZ loess due to microstructural differences
- Indeed, local studies (e.g. Carey *et al.* 2017) show that NZ loess can liquefy HOWEVER the loess tested in this study had a very high clay content (50% !).
- No NZ loess specific liquefaction resistance curve has been developed.

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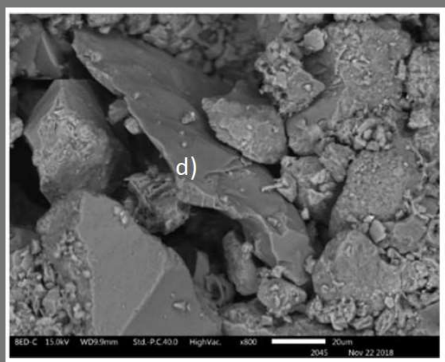
Research considerations – why is this important?

1. February 2011 earthquake occurred in Summer when slopes were relatively dry.
2. Climatic change may lead to wetter slopes in future, this means that the ongoing performance of loess slopes (with liquefaction considered) is not well understood. Indeed, recent studies by Yates & Russell (2020) show seasonal change in the hydraulic state of the loess.
3. Ongoing development & urbanisation is occurring throughout areas where loess is prevalent – understanding this fundamental soil behaviour will assist governing bodies in managing slope failures in future.



SEM image of Akaroa loess (Yates 2020)

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Research Plan

1. Literature review (ongoing!)
2. Extract intact block samples
3. Preparation of block samples for triaxial testing
4. Triaxial testing of intact and remoulded samples
    - Cyclic triaxial tests (5 – 7 tests)
    - Consolidated undrained monotonic triaxial test (1 – 2 tests)
    - Vs measurements before shearing (Bender Elements)
5. Interpretation of data & preparation of CSR-Nc plot

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References

Carey, JM, McSaveney, MJ & Petley, DN 2017, 'Dynamic liquefaction of shear zones in intact loess during simulated earthquake loading', *Landslides,* vol. 14, no. 3, pp. 789-804.

He, S, Wang, X, Fan, H, Wang, H, Ren, R & Guo, C 2020, 'The study on loess liquefaction in China: a systematic review', *Natural hazards (Dordrecht),* vol. 103, no. 2, pp. 1639-1669.

Karam, JP, Cui, YJ, Tang, AM, Terpereau, JM & Marchadier, G 2009, 'Experimental Study on the Cyclic Resistance of a Natural Loess from Northern France', *Soils and foundations,* vol. 49, no. 3, pp. 421-429.

Massey, CI, Yetton, MD, Carey, JM, Lukovic, B, Litchfield, NJ, Ries, W & McVerry, G 2013, *Canterbury Earthquakes 2010/11 Port Hills Slope Stability: Stage 1 report of the findings from investigations into areas of significant ground damage (mass movements)*, GNS Science Consultancy Report 2012/317

Pei, X, Zhang, X, Guo, B, Wang, G & Zhang, F 2017, 'Experimental case study of seismically induced loess liquefaction and landslide', *Engineering Geology,* vol. 223, pp. 23-30.

Wang, G, Zhang, D, Furuya, G & Yang, J 2014, 'Pore-pressure generation and fluidization in a loess landslide triggered by the 1920 Haiyuan earthquake, China: A case study', *Engineering Geology,* vol. 174, pp. 36-45.

Yates, K 2020, *An investigation of the soil-water characteristics and unsaturated shear strength behaviour of Akaroa loess*, PhD Thesis, University of canterbury,

Yates, K, Fenton, CH & Bell, DH 2018, 'A review of the geotechnical characteristics of loess and loess-derived soils from Canterbury, South Island, New Zealand', *Engineering Geology,* vol. 236, pp. 11-21.

Yates, K, Russell, A R. 2022. The unsaturated characteristics of natural loess in slopes. *Geotechnique (In press)*

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Thank you

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