Geotechnical characterization of New Zealand volcanic soils for land reclamation purposes

Shaurya Sood, Gabriele Chiaro, Thomas Wilson, Mark Stringer

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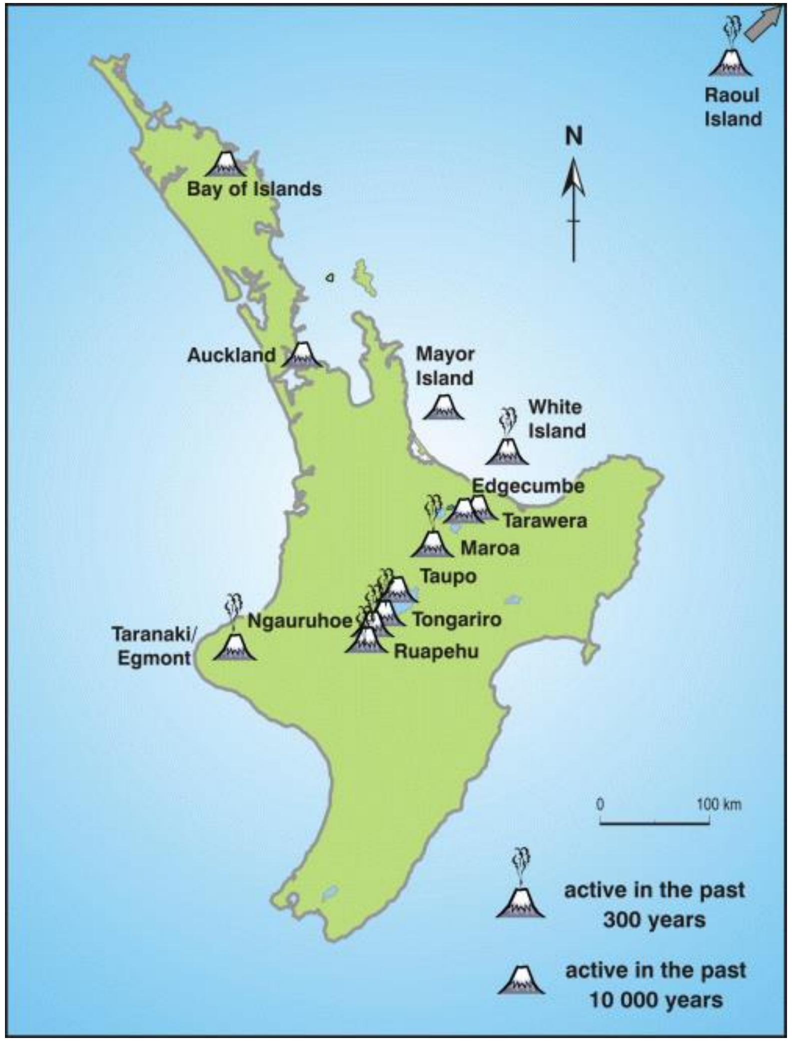
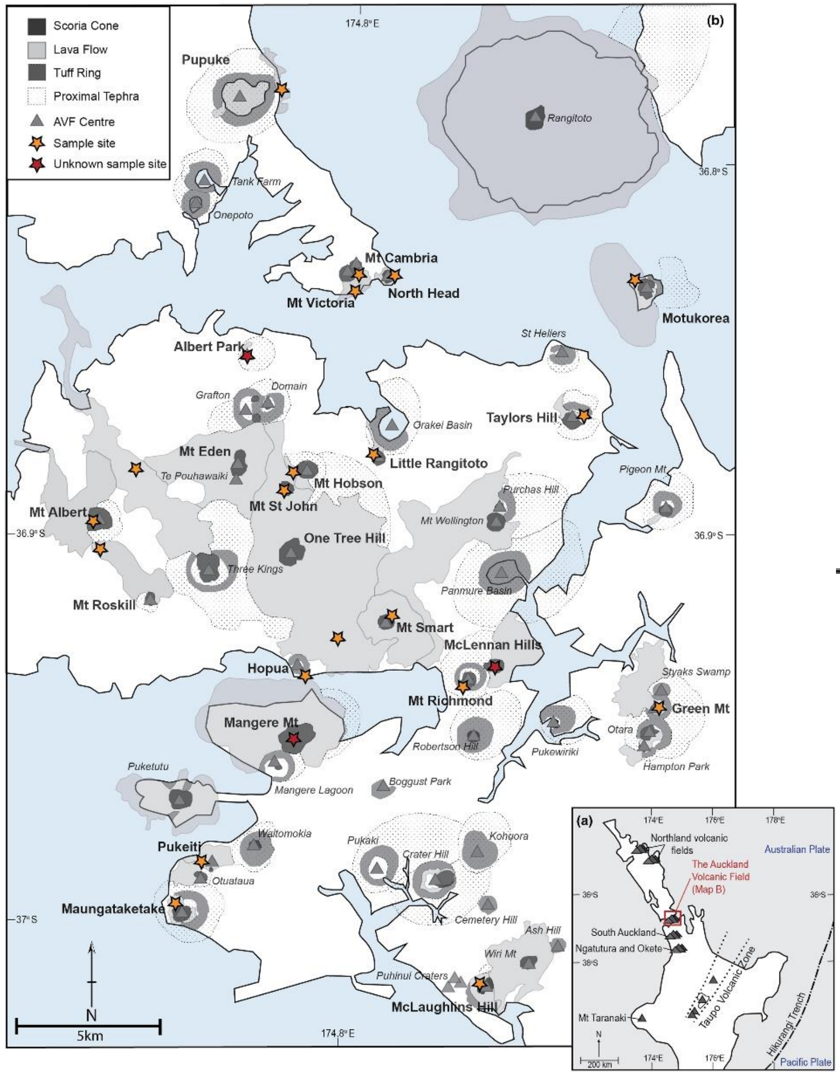
Background



Volcanic activity in North Island and offshore of New Zealand (GNS Science)



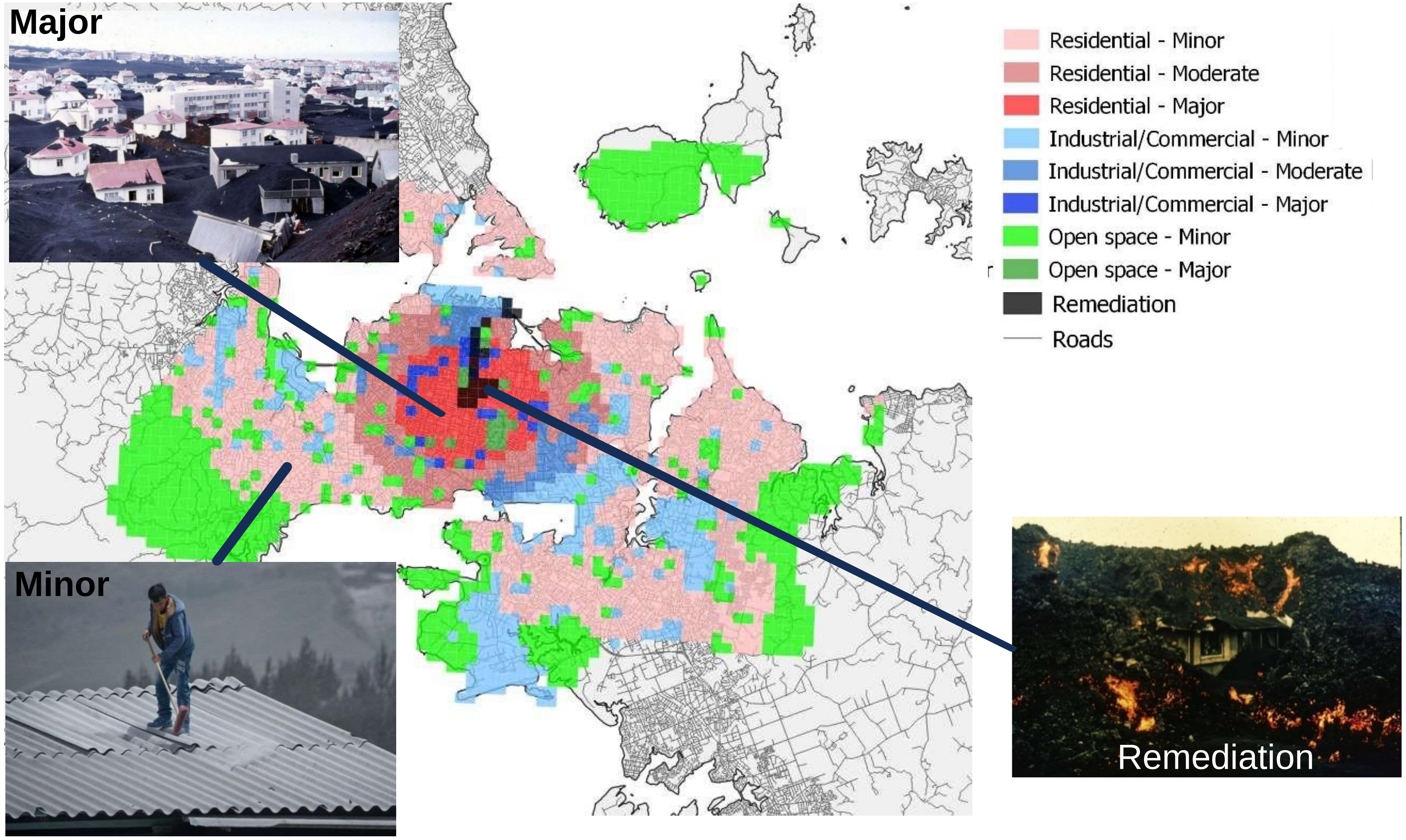
Auckland Volcanic Field (Leonard et al., 2017)

Background

- 6 million tonnes of building debris (complex mixed waste)
- 10 – 15 million tonnes of volcanic products (ash, lava, etc. to deal with)
- Total: 25 – 30 million tonnes

Comparison

- Canterbury EQ: 7.5 million tonnes
- Tohuko EQ/Tsunami: 30 million tonnes



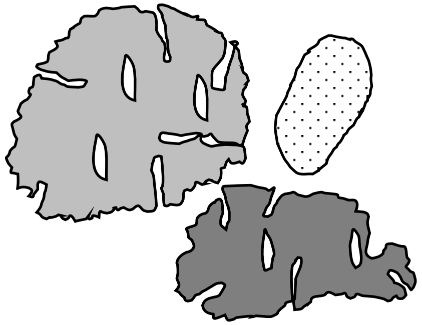
Clean up of Urban Areas (Mt. Eden Scenario) after Volcanic Eruptions (Hayes et al., 2020)

Scope

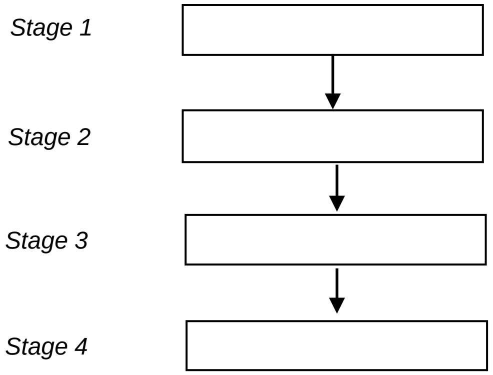
- After eruption clean-up, the **storage** of these volcanic deposits becomes a point of concern

- Utilization of volcanic soils for **geotechnical purposes** such as – **land filling**, embankments, foundations *but…*

- **Vast diversity in volcanic soils characteristics – gradation, minerals**

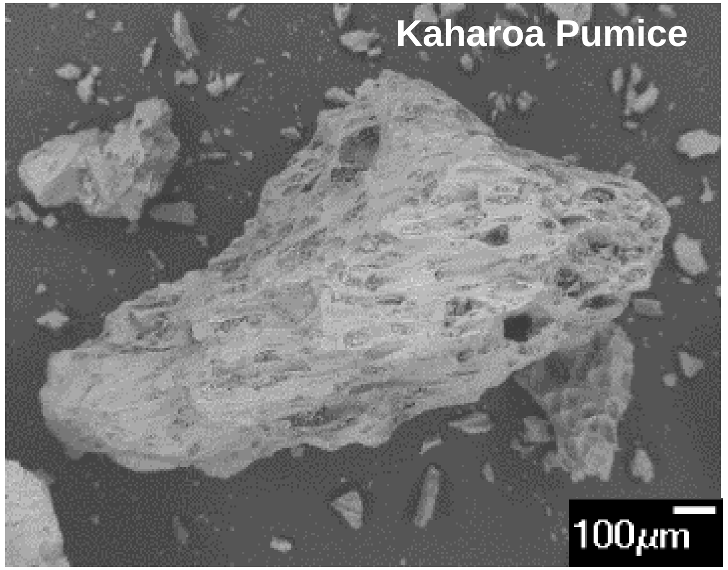


- **No simple geotechnical characterization procedure**

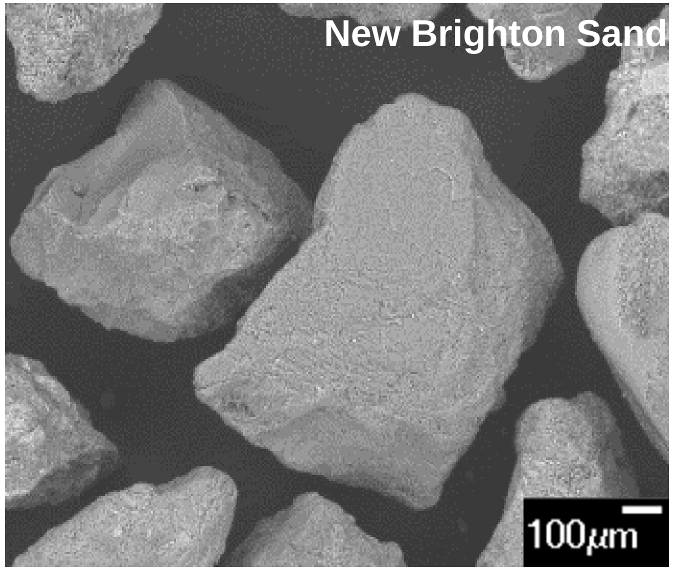


What makes Volcanic Soils different from Hard-Grained soils?

- Volcanic soils are **non-conventional** or different from normal hard grained soils
- Due to their formation processes, they constitute pores or voids within their structure
- The **internal pores** or voids makes them **crushable**
- **Concerning from engineering point of view**



Angular**, vesiculated** - structure of **Kaharoa Pumiceous Sand**

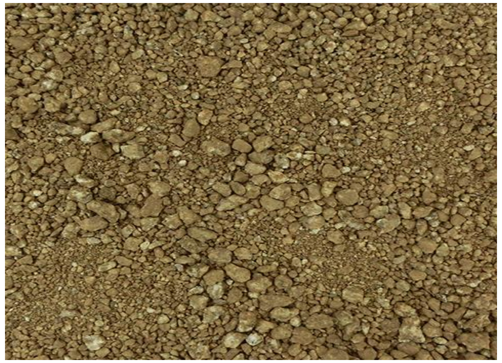


Sub-rounded, **non-vesiculated** structure of **New Brighton Beach Sand**

Geomaterials used in Civil Engineering applications

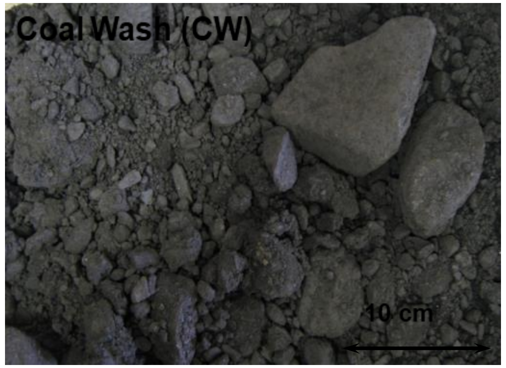
Beach Sand

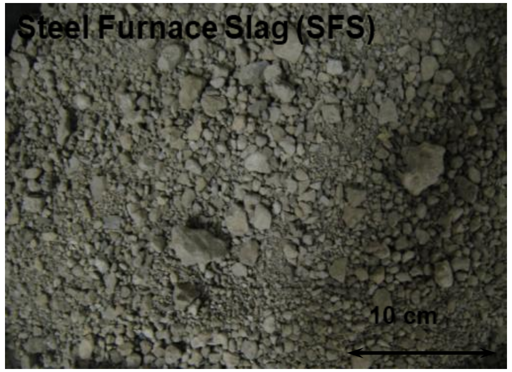
Gravel



Masado (decomposed granite) – (Source: http://www.ono-kai.com/pit-sand)

Shirasu (volcanic soil) – (Suzuki and Yamamoto, 2004)

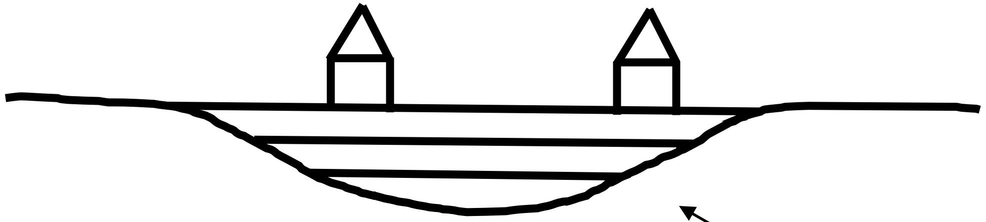




Coal wash and Steel Furnace Slag (Chiaro et al., 2015)

Comparable performance of volcanic soils against standard soils?

Geotechnical parameters for landfill



Inland land filling

Embankments

Compacted land fill with volcanic soil

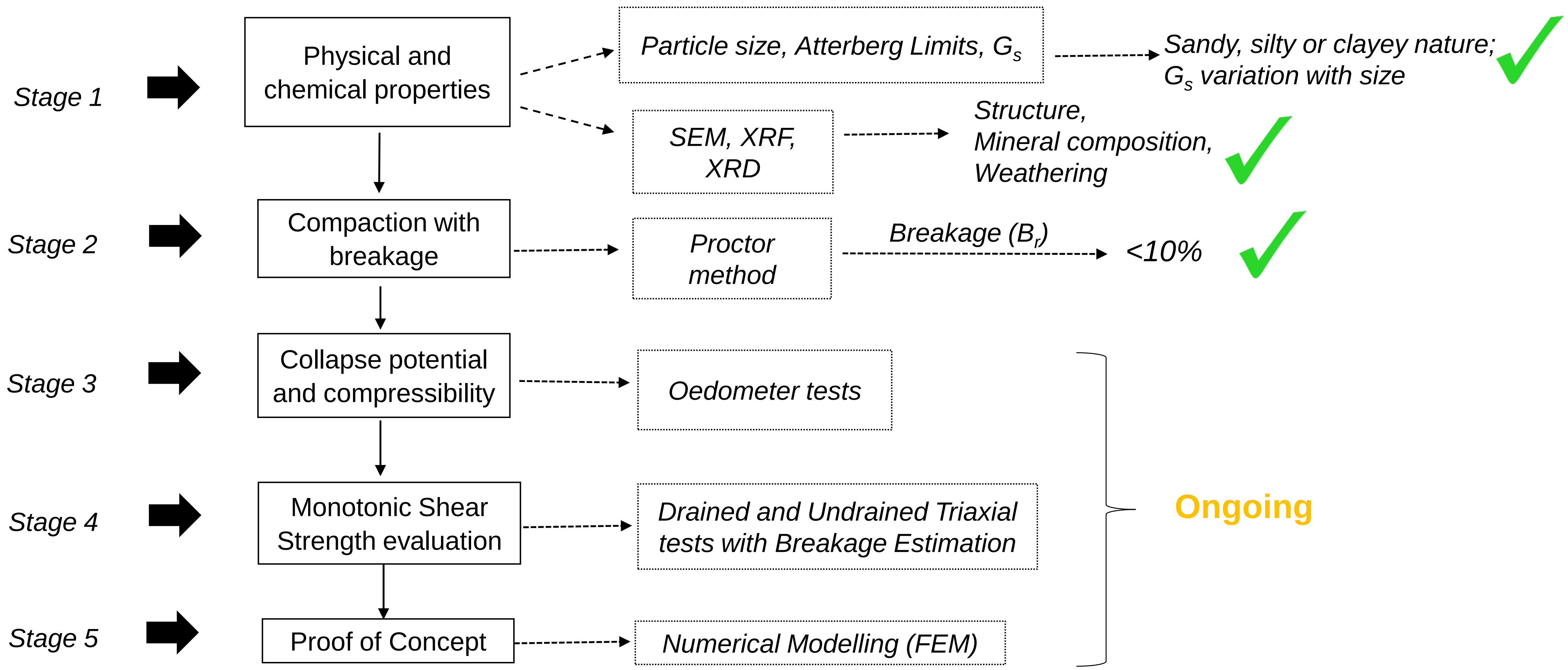
Soil Sampling – Selection of soil samples

Physical and Chemical Properties

Compaction parameters

Shear strength

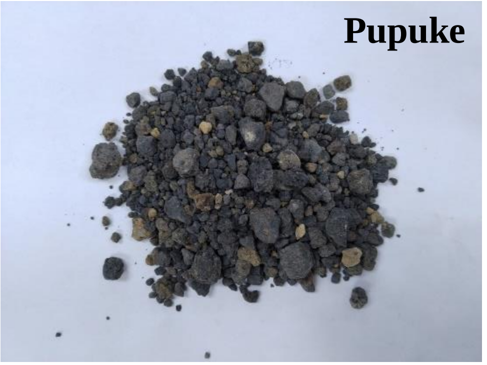
Methodology - Development of geotechnical parameters for compacted land fill design



Eruption scenarios and typical soil samples collected

Mt. Tarawera "Recent" eruptions

- **0.80ka** (rhyolitic) – Kaharoa (1300)
- **0.13ka** – Tarawera (basaltic), Rotomahana mud (thermally altered rhyolite) – Tarawera 1886

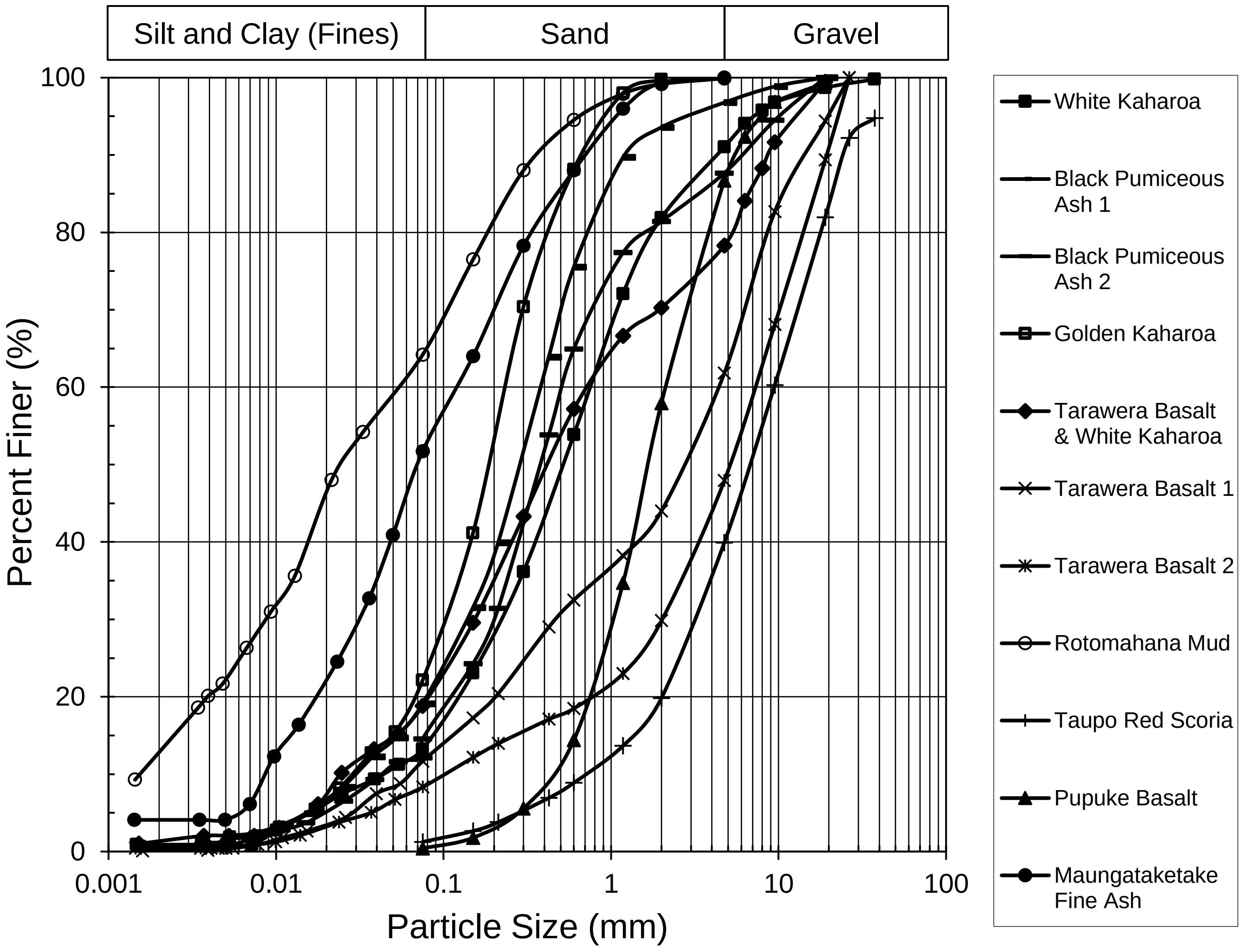


Auckland "Older" eruptions

- **140ka** – Pupuke (basaltic)
- **85ka** – Maungataketake (basaltic)

Experimental results - Particle Size Distribution

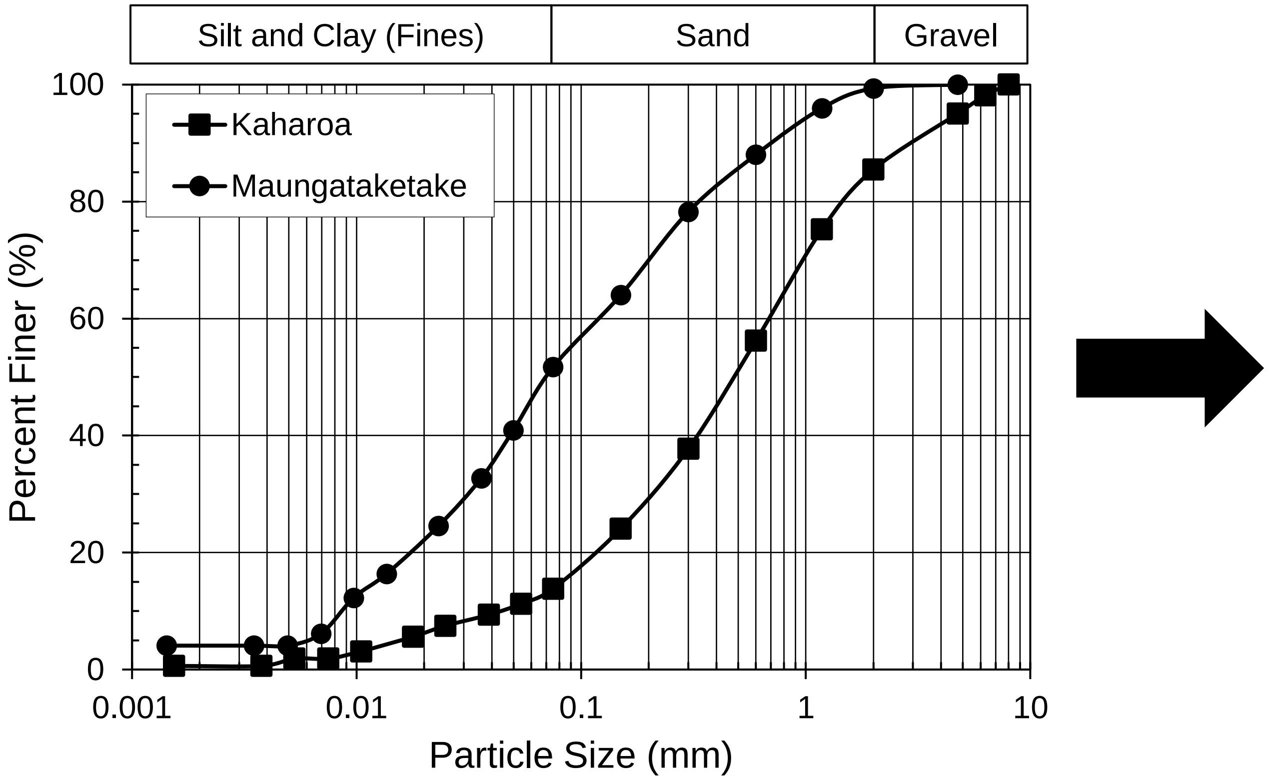
Being **airfall** deposits, majority of them are **well-graded silty sands** with varying proportions of **fines and gravel**



Grain Size Distributions of Volcanic Soils Collected

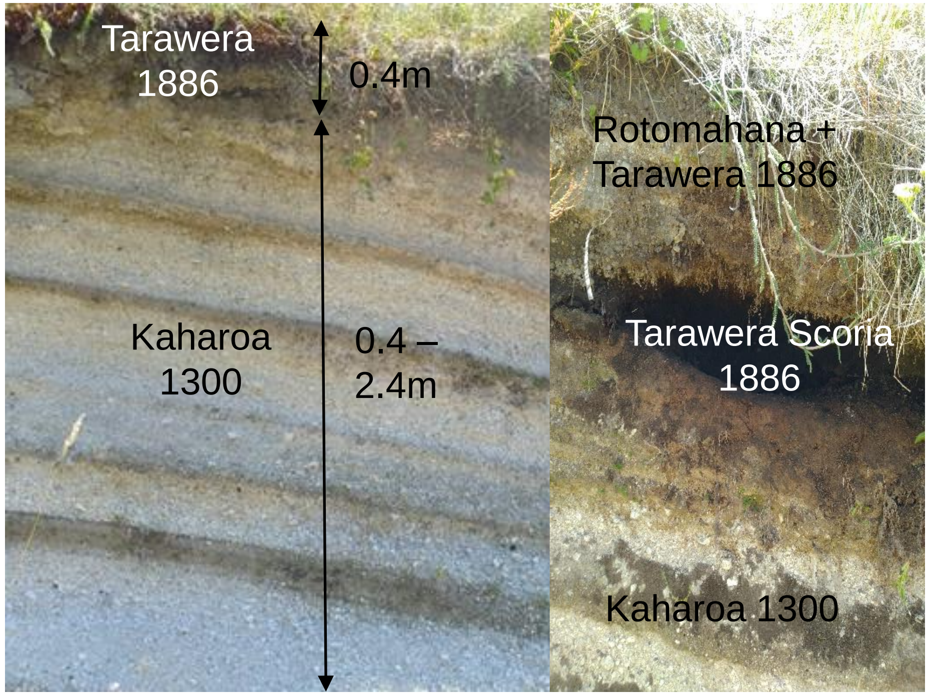
Particle Size Distribution (Kaharoa and Maugataketake)

Soil Sample	Gravel (%)	Sand (%)	Fines (%)	PI (%)	D_{max} (mm)	D_{50} (mm)	C_u	C_c	Soil Classification
Kaharoa	**4.9**	**81.2**	**13.8**	NP	8.0	0.50	16.3	1.5	Silty Sand (SM)
Maungataketake	**-**	**48.3**	**51.7**	3.7	4.75	0.07	14.5	0.9	Sandy Silt (ML)

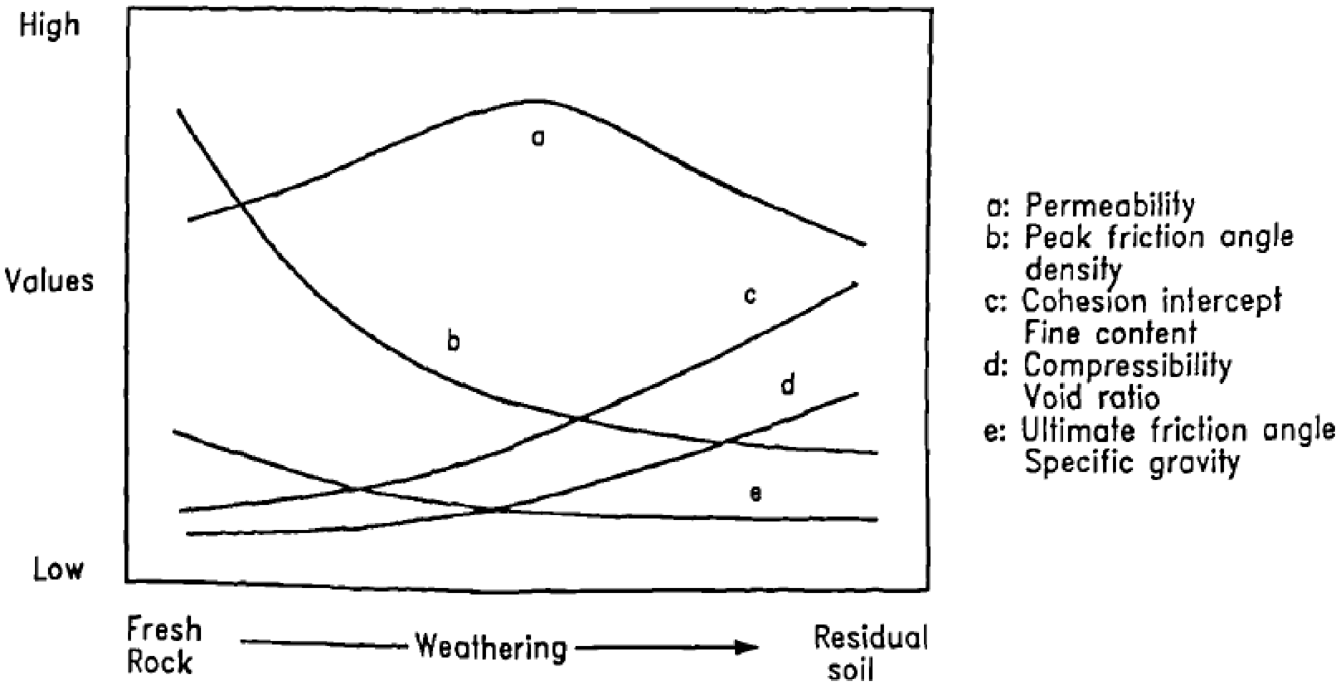


- **Well-graded materials**
- **Maungataketake finer than Kaharoa**

Role of Mineralogy in Estimating Geotechnical Behaviour



Different eruptions – **different deposits** changes in mineralogy (e.g. – Tarawera 1300 & 1886)

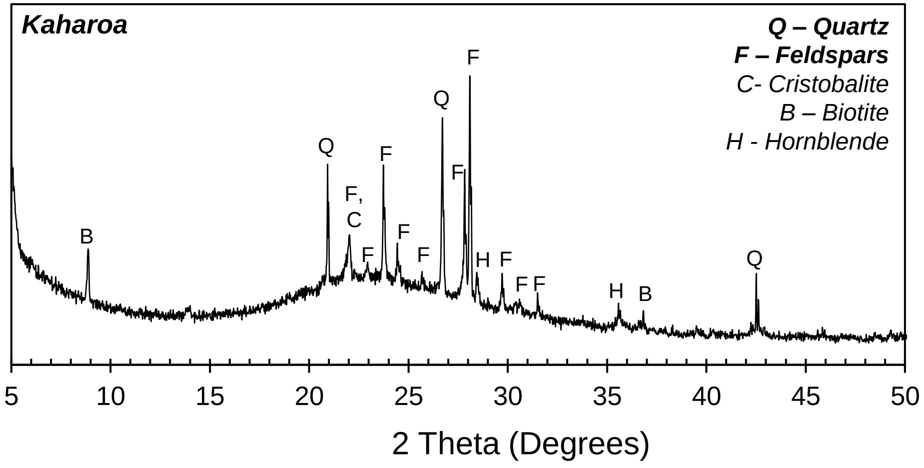


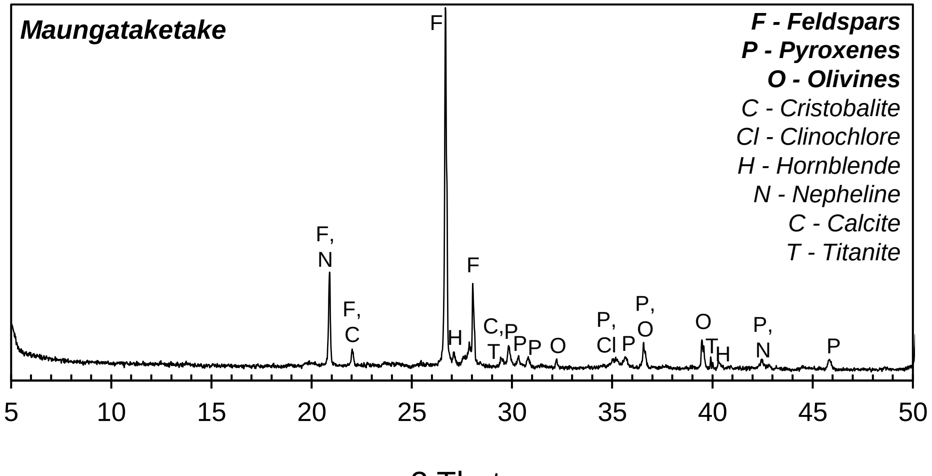
Old or recent deposits - Lee, I.K. (1991, PhD Thesis)

Experimental results - Chemical and Mineralogical analyses (Kaharoa & Maungataketake)

Soil	XRF - Major Oxide (Wt. %)										
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
Kaharoa	75.10	0.15	12.27	1.30	0.06	0.23	1.11	3.90	3.38	0.04	2.02
Maungataketake (with sandstone)	57.26	1.37	12.29	8.30	0.11	5.23	6.60	2.44	1.64	0.38	4.00

XRD - Mineral (Wt%)	Soil	
	Kaharoa	Maungataketake
Glass	79.78	44.93
Quartz	3.76	-
Cristobalite	0.40	2.74
Feldspars	14.97	27.42
Biotite	0.71	-
Hornblende	0.32	2.04
Hematite	0.05	0.13
Magnetite	-	-
Pyroxenes	-	9.22
Olivines	-	3.74
Clinochlore (Chlorite)	-	5.84
Nepheline	-	0.55
Epidote	-	0.95
Spinel	-	0.44
Apatite	-	0.96
Calcite	-	0.33
Titanite	-	0.73
Total Crystal Content	20.22	55.07
Feldspars / (Quartz + Cristobalite)	3.60	10.00

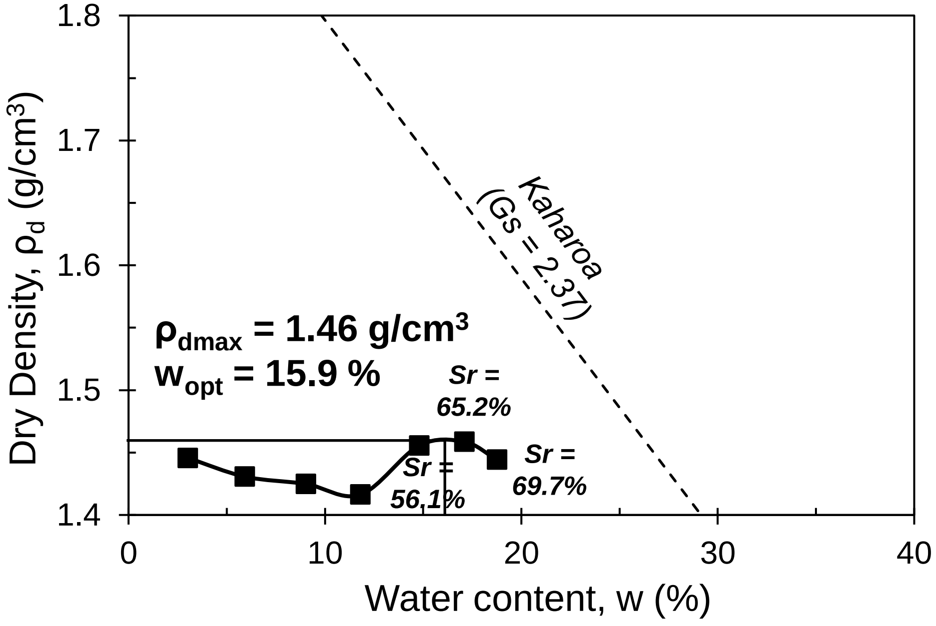


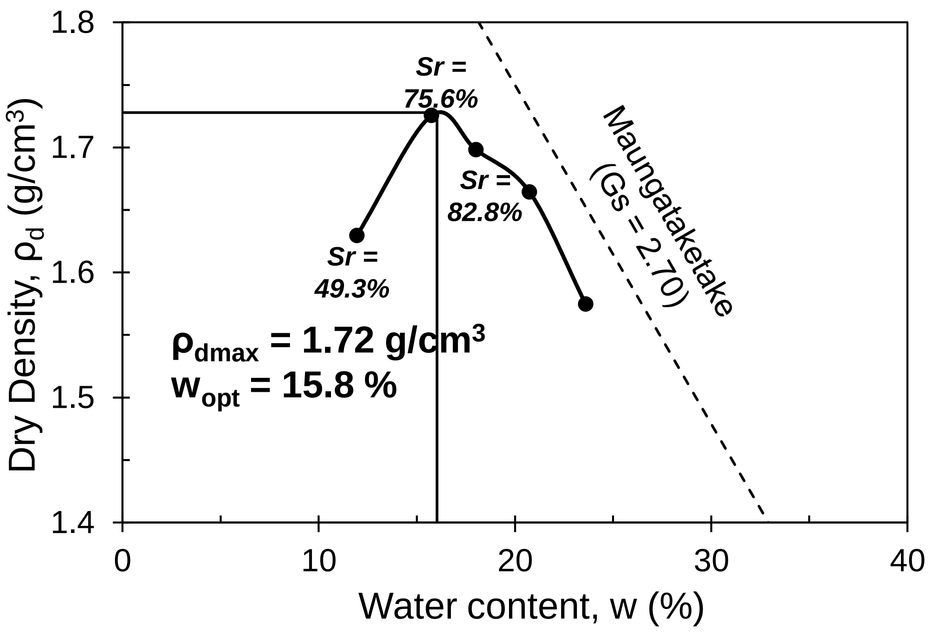


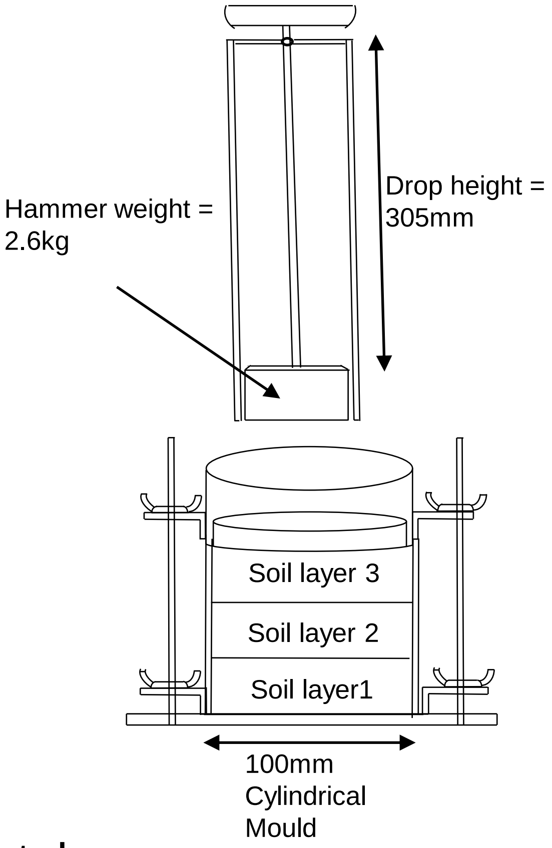
Kaharoa **less weathered than** Maungataketake

Experimental results – Compaction and Breakage properties (Kaharoa & Maungataketake)

Compaction parameters – Dry density and water content



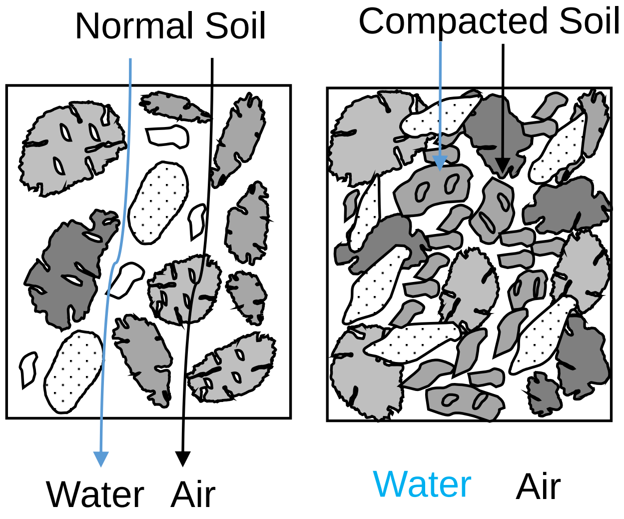


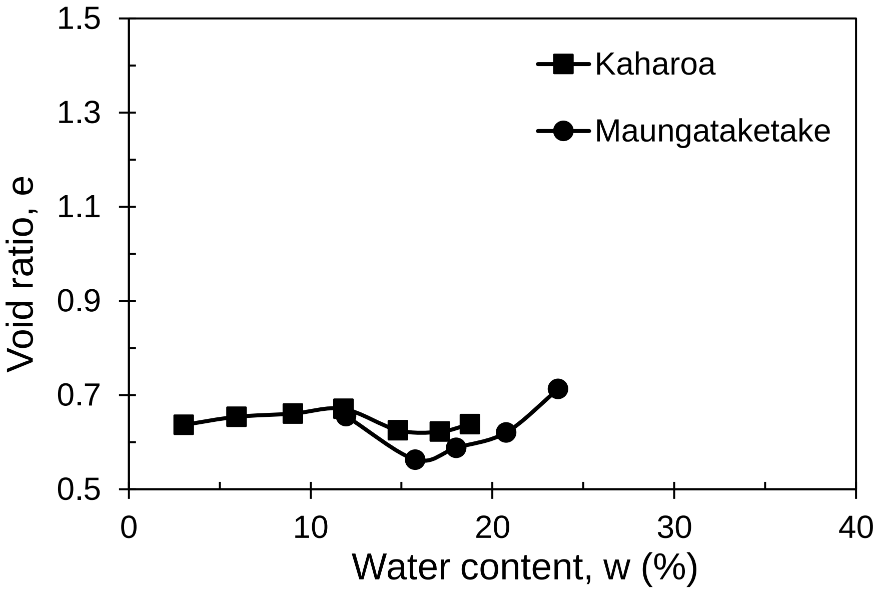


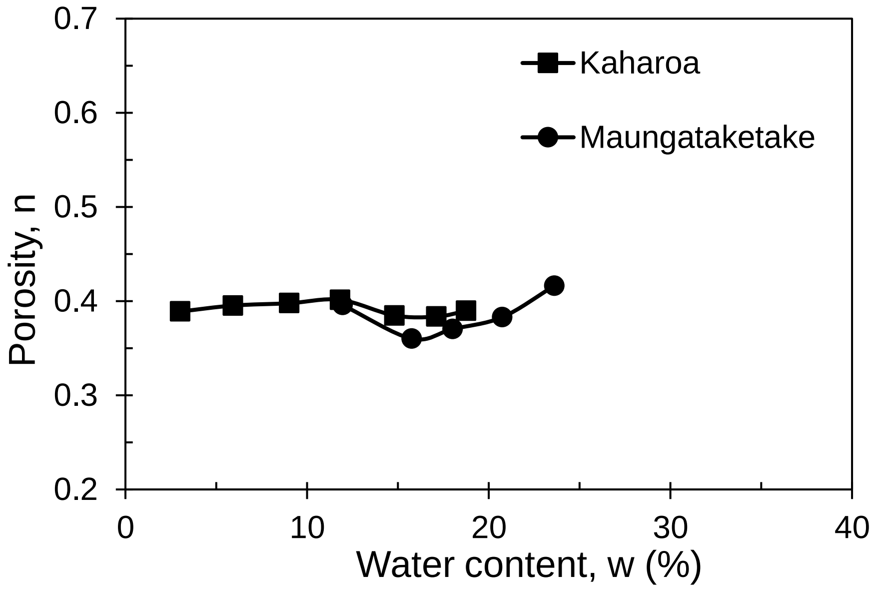
Flat compaction curve of Kaharoa in comparison to **well-shaped curve** of Maungataketake (**slity sand with little clay** nature of latter in comparison to **silty sandy** nature of former)

Experimental results – Compaction and Breakage properties (Kaharoa & Maungataketake)

Compaction parameters – Void ratio and porosity





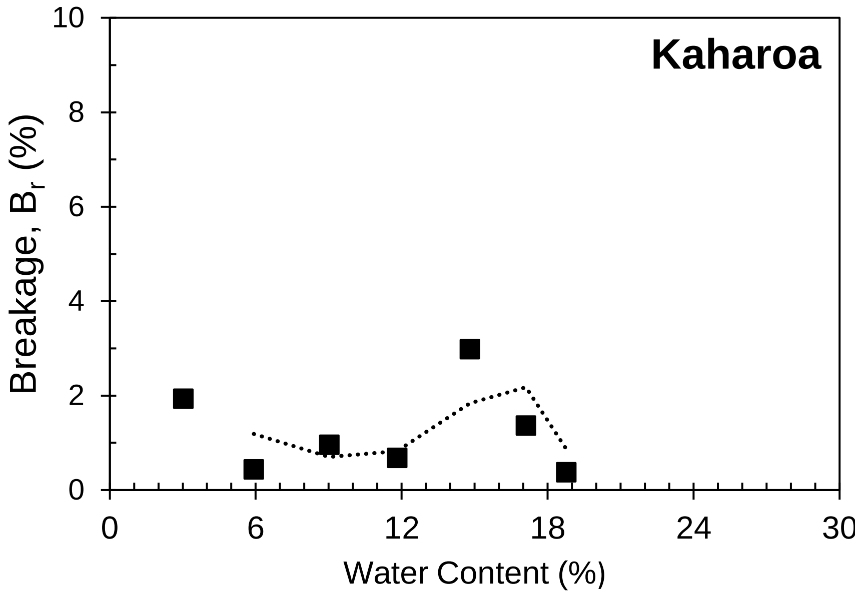


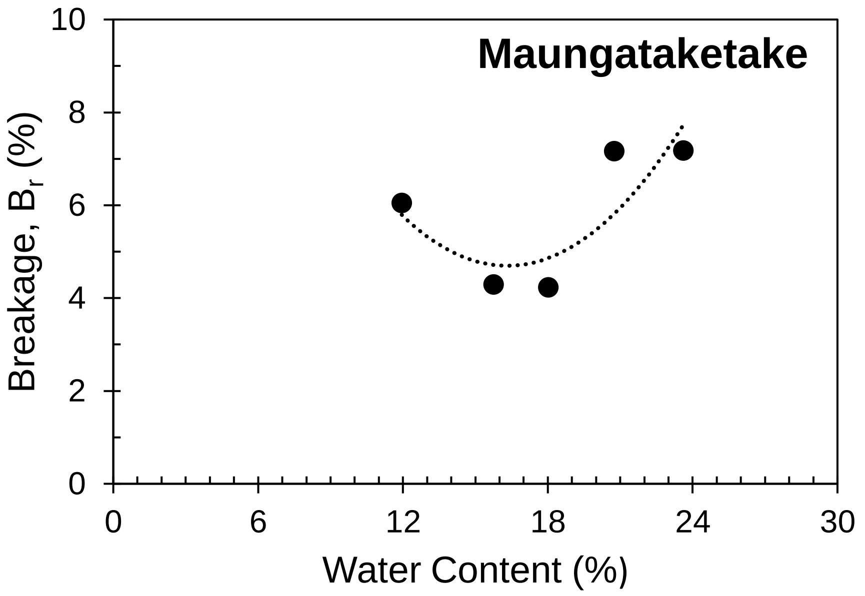
For silty sands

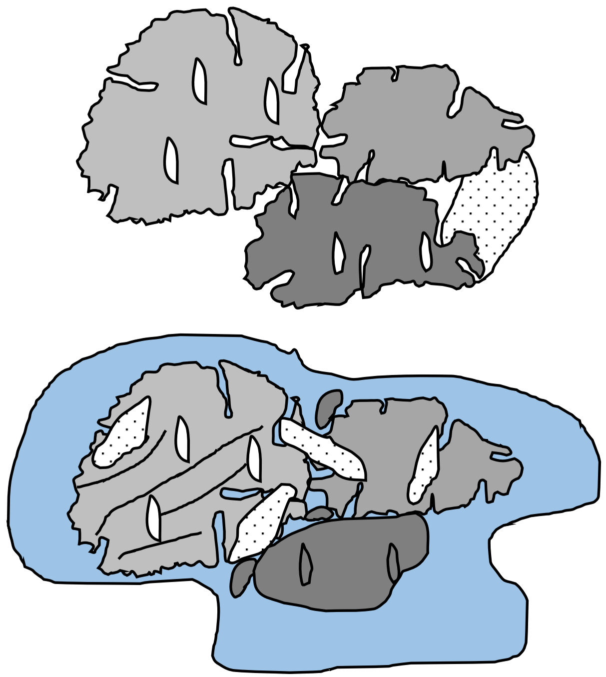
- **Void ratio "e" range: 0.25 – 1.80**
- **Porosity "n" range: 0.2 – 0.65%**

Experimental results – Compaction and Breakage properties (Kaharoa & Maungataketake)

Breakage B_r estimation – Hardin's method 1985





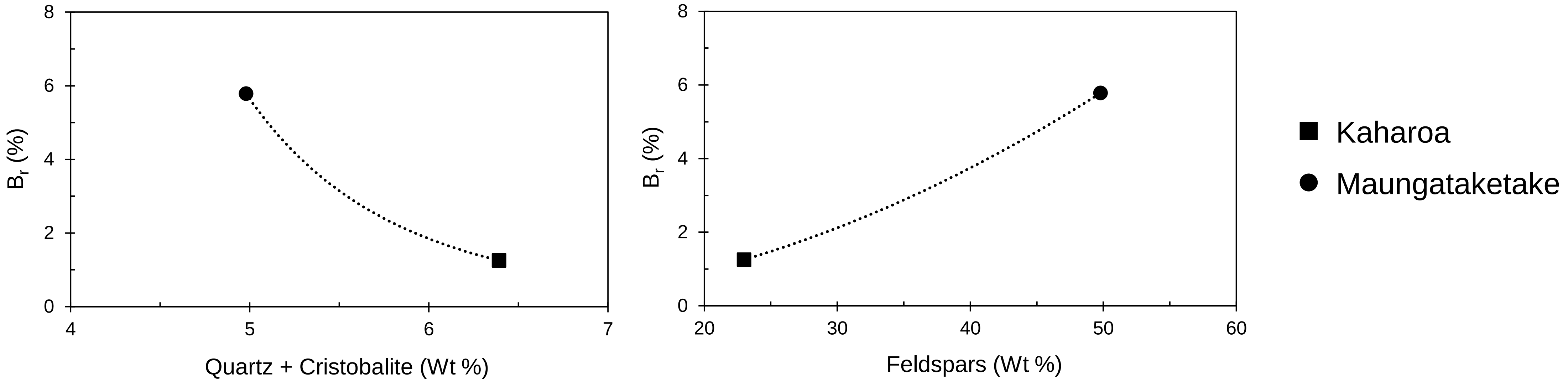


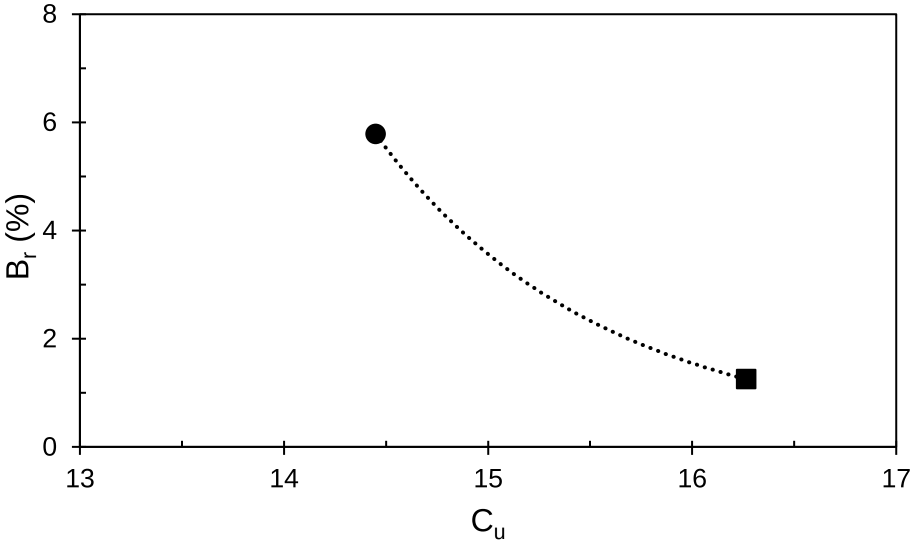
Avg. B_r (Kaharoa) = 1.25%, Avg. B_r (Maungataketake) = 5.78%

< 10% using Standard Compaction

Lesser breakage in Kaharoa than Maungataketake – stronger matrix

Experimental results – Effect of Mineral Content and Gradation on Compaction and Breakage





Kaharoa less weathered and relatively **coarser** than **Maungataketake**, shows **lesser breakage** upon compaction

Preliminary Conclusions and Implications

- **Well-graded** nature of these materials – easier to compact and put in field

- Volcanic soils differ in their geotechnical properties based on the **magma types, geo-chemistry** *(Kaharoa rhyolitic, Maungataketake basaltic)* **and pre and post depositional conditions** – therefore, not easy to define their behaviour!

- The extent of weathering ***(mineralogy)*** *and* ***depositional environments*** are dominating factors when we take into account volcanic soils:

  - Effect of clay and silt sized ***(finer)*** fractions (tighter matrix, higher density as for Maungataketake)
  - ***Minerals*** (quartz, feldspars predominant) – quartz being harder (resists breaking as for Kaharoa)
  - Near to vent **deposition** – coarser fragments (as in Kaharoa)

Ongoing and further investigation

- Shear strength
- Collapsibility

Triaxial apparatus

Ongoing and further investigation

Compacted volcanic soils

Design Criteria Development

Numerical Model (Proof-of-concept)

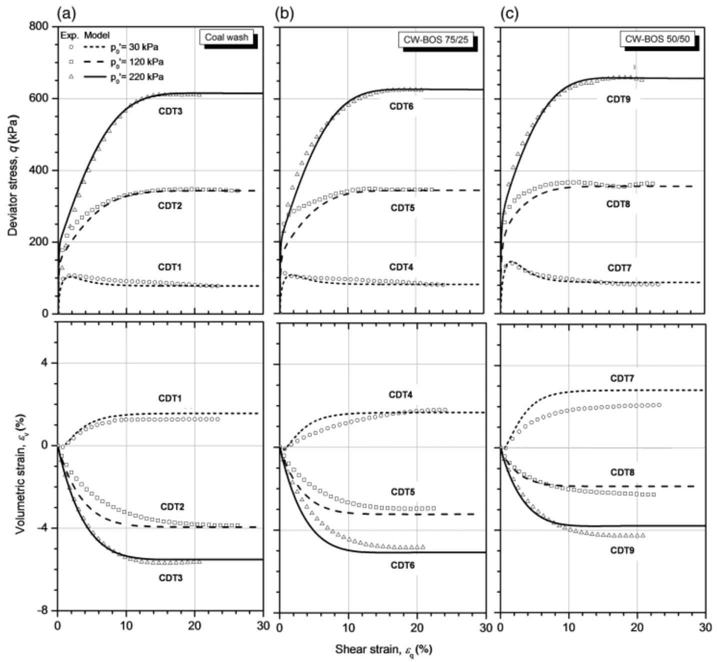
Stage 1: Physical and Chemical Properties — Dominant size fraction, weathering degree → **Well-graded, recent/older**

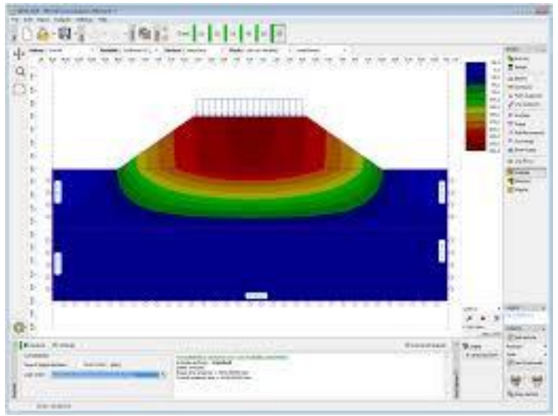
Stage 2: Compaction — Workable densities with water, post compaction breakage → **B_r < 10%**

Stage 3: Collapsibility — Ingress of water action

Stage 4: Shear strength — Friction angle

Stages 3–4: **Ongoing**





***Stages cleared with appreciable level of results**

Acknowledgments

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Thank you!