# Sensitivity in volcaniclastic silts in North Island, New Zealand

## Sensibilité des limons volcanoclastiques de l'Île du Nord en Nouvelle-Zélande

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ABSTRACT

New Zealand soils of volcanic and volcaniclastic origin are often sensitive to remoulding, having a high ratio of peak to remoulded strength. This study has focused on silty, air-fall deposits related to the eruption of the Kidnappers ignimbrite. A field shear vane was used to measure shear strength at field exposures. Samples were taken to complete more detailed testing in a laboratory environment including Atterberg limits, drained and undrained triaxial strength, and ring shear testing. Samples were also collected for X-Ray diffraction and scanning electron microscopy to study the mineralogy and microstructure of the soils. Comparisons are drawn between New Zealand sensitive soils and those from Canada and Norway.

RÉSUMÉ

Les sols de Nouvelle-Zélande d'origine volcanique et volcanoclastique sont souvent sensibles au remaniement, du fait de leur taux élevé de résistance maximale par rapport à la résistance remaniée. Cette étude se concentre sur les projections de dépôts limoneux liés à l'éruption de l'ignimbrite Kidnappers. Un scissomètre de cisaillement de terrain a été utilisé pour mesurer la résistance au cisaillement à des expositions de la zone. Des échantillons ont été prélevés pour procéder à des essais en laboratoire plus détaillés, comme les limites d'Atterberg, la résistance triaxiale drainée et non drainée, et le test de cisaillement circulaire. Des échantillons ont également été collectés en vue de diffraction par rayons X et pour scanner la microscopie des électrons afin d'étudier la minéralogie et la microstructure des sols. Des comparaisons sont établies entre les sols sensibles de Nouvelle-Zélande et ceux du Canada et de Norvège.

Keywords : sensitive soils, volcanic soils, triaxial testing, index properties

## 1 INTRODUCTION AND BACKGROUND

Soil sensitivity is a curious property of some soils where the soil's remoulded strength is much lower than its peak strength. High sensitivity in soils frequently causes large, retrogressive landslides in Canada and Norway (Eden and Mitchell 1973; Kenney and Drury 1973; Gillot 1979; Lawrence et al. 1996; Demers et al. 2000). These soils are commonly glacially derived, marine deposited clays whose sensitivity is related to flocculated deposition and a subsequent removal of salts from the pore water. Sensitive soils in New Zealand are formed under very different processes. The soils studied in this project are all of volcanic origin and of rhyolitic (high silica) composition. This study has focused on the air-fall products of the 1 Ma Kidnappers eruption from Mangakino caldera deposited near the city of Tauranga (Fig. 1) (Shane 1994; Schipper 2004).

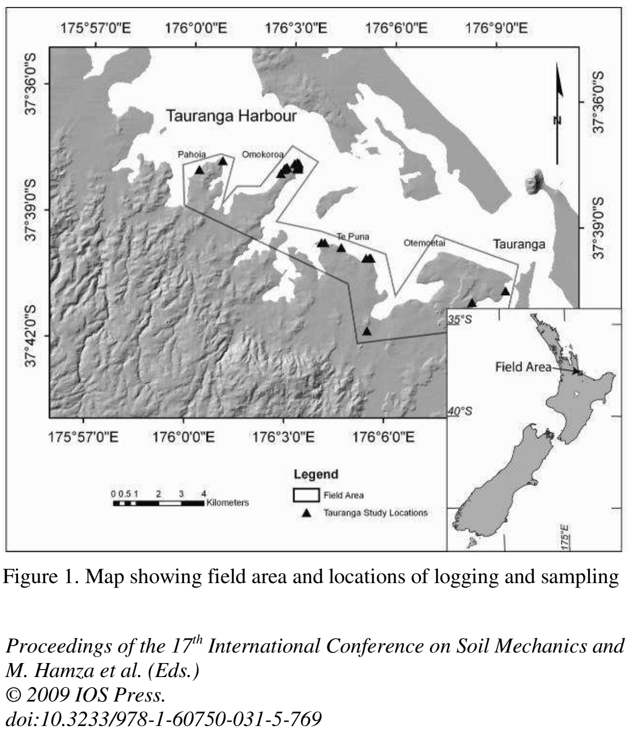


Figure 1. Map showing field area and locations of logging and sampling

Similar deposits have been involved in a number of major slope failures in the past, most notably the Ruahihi Power Scheme failure (Prebble 1984; Burns and Cowbourne 2003) and the Bramley Drive failure (Gulliver and Houghton 1980). Smaller landslides are common during periods of heavy rain (Dellow 2005). These landslides are characterized by a high degree of remoulding of the landslide mass and long run out distance.

Sensitive soils in New Zealand have been previously studied by Smalley et al. (1980) and Jacquet (1990). The study by Smalley et al. (1980) is limited to a brief assessment of the shear strength ratio and mineralogy of the soils in question. Jacquet (1990) went into somewhat more detail, but focused on andesitic tephras from Mt. Taranaki. These two studies do serve to highlight the widespread distribution of sensitive soils in the North Island of New Zealand. The goal of this research is to study in detail deposits of a single age, origin, and starting mineralogy to more closely examine the effects of deposition and weathering in the development of sensitivity.

## 2 DESCRIPTION OF SOILS

The soils in this study are generally clayey silts, sometimes containing very fine sand sized pumice fragments. The original

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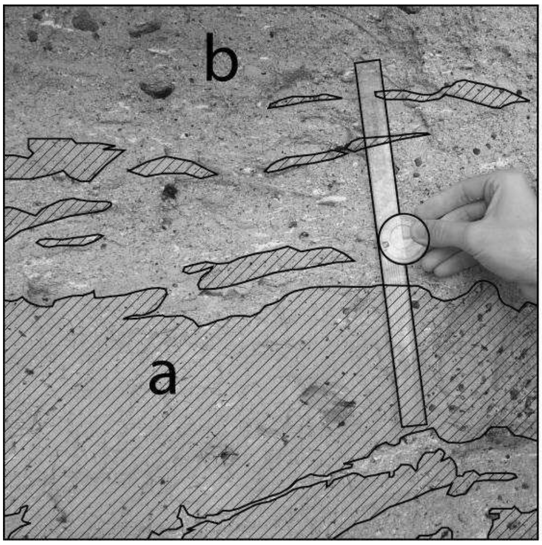


Figure 2. Example of sensitive soil from Pahoia with complex bedding. Scale is approximately 30 cm. a.) highly sensitive pink clayey silt b.) light greyish brown silty sand with clay, with white gravel sized pumice fragments. Pumice fragments break down into a silty clay with sand upon remoulding.

Table 1. Shear vane data

| Sample Number - Location | Peak Shear Strength (kPa) | Remolded Shear Strength (kPa) | Sensitivity |
|---|---|---|---|
| 20 - Om | 68 | 3 | 23 |
| 21 - Om | 80 | 1 | 80 |
| 24 - Om | 136 | 16 | 9 |
| 36 - Om | 56 | 4 | 14 |
| 37 - Om | 120 | 24 | 5 |
| 38 - TP | 116 | 6 | 19 |
| 41 - Pa | 136 | 18 | 8 |
| 42 - Pa | 140 | 12 | 12 |
| 43 - Pa | 260 | 16 | 16 |

texture of these soils was likely dominated by volcanic glass, which has now largely weathered to clay minerals. Crystal grains include quartz, plagioclase, hydromica, and hornblende. These crystals are usually of fine to very fine sand size, but sometimes range up to medium sand. In some locations, gravel-sized pumice fragments are visible in outcrop; however, these fragments are heavily weathered and break down into a mixture of clay and crystal fragments upon remoulding.

Bedding and deposition of these soils is usually complex with decimetre scale variation in grain-size and geotechnical properties (Fig. 2). This variation can make sampling difficult, especially due to the problem of obtaining a truly representative sample. For this reason, a hand shear vane was used in the field to make an estimation of shear strength during sampling. Field shear vane data from Omokoroa, Pahoia, and Te Puna is presented in Table 1.

## 3 GEOTECHNICAL PROPERTIES

Geotechnical testing was conducted in the Geomechanics Lab, Faculty of Engineering, University of Auckland. The tests

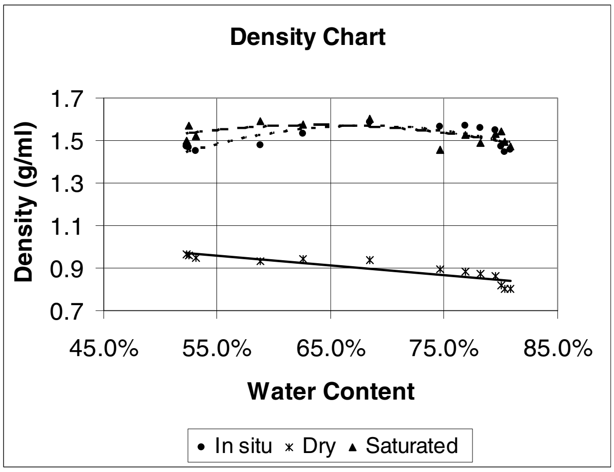


Figure 3. Natural water content and density of triaxial specimens at in situ, saturated, and oven-dried conditions

performed include density, moisture content, drained and undrained triaxial shear, ring shear, and Atterberg limits.

Density of soils was determined by dividing the mass of a carved cylindrical specimen by its volume, measured with a calliper. Moisture content (by mass) and Atterberg limits tests were performed in compliance with New Zealand Standard 4402:1986 (Standards Association of New Zealand 1986). Field moisture content was preserved by wrapping samples in multiple layers of plastic wrap or storage in plastic zipper bags.

The density of the soils studied is relatively low and does not vary much between locations (Fig. 3). This, in addition to the nature of field exposures indicates that only a small amount of consolidation has taken place since the deposition of these soils. The moisture content of the soils ranges from 52% to 81%, but in nearly all cases is above the liquid limit of the soil as determined by the Atterberg limits tests.

Using the Cassagrande chart classification, most of these soils are high plasticity clayey silts (Fig. 4). A few classify as intermediate-plasticity silts, and one as a high plasticity silty clay. This is of interest, because most of the sensitive soils from Canada and Norway plot about the "A"-line in the Cassagrande chart (Dascal et al. 1973; Gillot 1979; Eden and Law 1980).

The results of drained triaxial tests are presented as a p'-q plot in Figure 5. The friction angle ranges between 30º and 40º, and the cohesion between 0 and 80 kPa at the range of confining pressures used (typically 50 kPa to 300 kPa). Stress paths for the undrained tests are presented in Figure 6. These tests follow

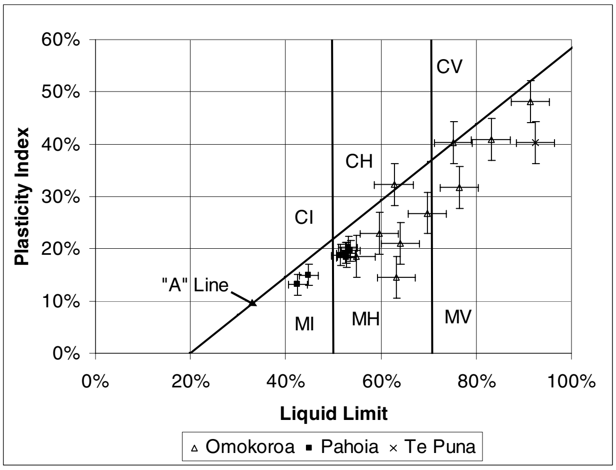


Figure 4. Cassagrande Classification chart with error bars from NZ Standard 4402:1986

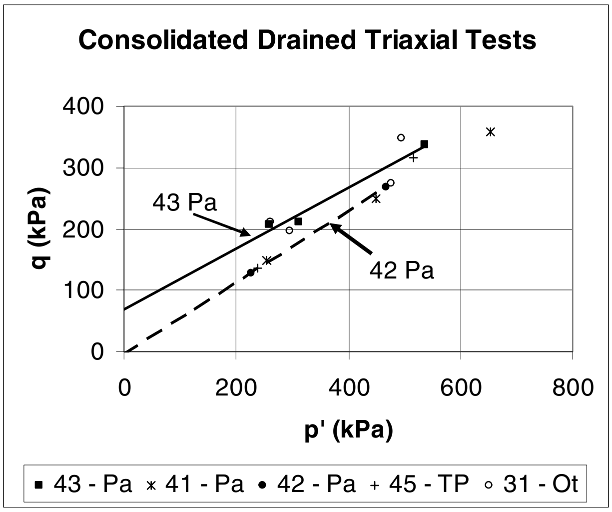


Figure 5. Consolidated drained tests by sampling location: Pa - Pahoia, TP - Te Puna, and Ot – Otemoetai

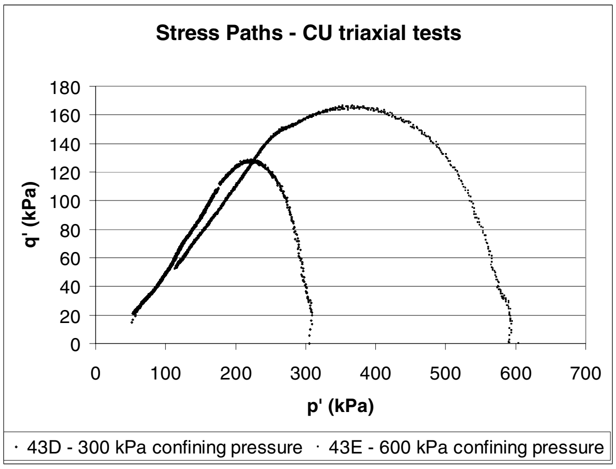


Figure 6. Stress paths from undrained tests of samples from Pahoia

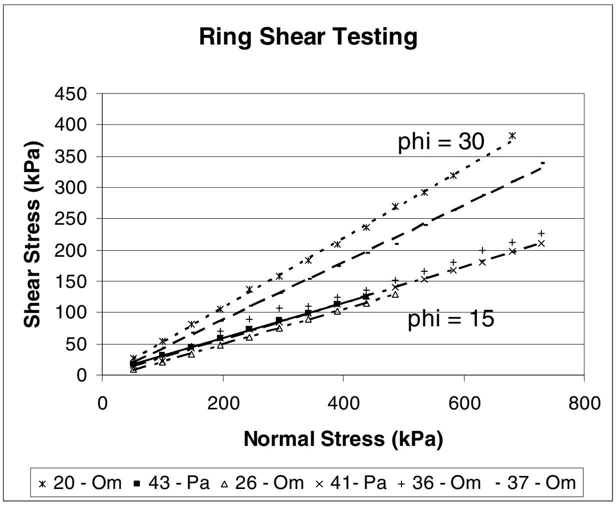


Figure 7. Residual shear strength envelope. Locations Om - Omokoroa, Pa - Pahoia

a stress path typical for normally consolidated clay material, which is to be expected based on their density and plasticity. The results of these tests are summarized in Table 2.

Table 2. Laboratory undrained shear strength results, samples taken from two locations.

| Specimen | Shear Strength (kPa) |
|---|---|
| 24a-Om | 181 |
| 24b-Om | 149 |
| 24c-Om | 153 |
| **24-Avg.** | **161** |
| 43a-Pa | 129 |
| 43b-Pa | 163 |
| **43-Avg** | **146** |

A Bromhead (1979) style ring shear apparatus was used to determine the residual friction angle of the soil samples collected (Fig. 7). The samples from Pahoia are tightly clustered near 30° and 15° for the peak and residual cases, respectively. The residual friction angle of samples from Omokoroa are more variable.

## 4 MINERALOGY AND MICROSTRUCTURE

Clay mineralogy of specimens was determined by X-ray diffraction. Diffraction patterns of clay mounts are dominated by kaolin group minerals, especially halloysite and kaolinite. There is also a possibility that allophane is present in these samples; however, allophane is amorphous to X-rays and could not be identified by this method.

A scanning electron microscope (SEM) was used to investigate the microstructure of the soil samples collected. A typical photomicrograph is presented in Figure 8. As reworked volcanic materials, there is difficulty in describing or classifying them in schemes designed for either sedimentary or volcanic materials. The examples of Grabowska-Olszewska (1984), Moon (1993), and Selby (1993) were used together to describe these soils. The soils are similar to matrix microstructure clay soils, where a significant portion of the silt grains are composed of volcanic glass fragments.

## 5 DISCUSSION

The major difficulty encountered during this study involved the use of the hand shear vane to measure shear strength in the field. The shear vane is designed to measure the undrained shear strength of saturated clays. The soils that were studied in this research do not fit those conditions. From the limited number of undrained triaxial tests conducted, the shear vane results do not appear to be reliable as a measurement of the actual shear strength; however, the shear vane would appear to still be useful as a relative measure of shear strength within generally similar soils. In general, the shear vane overestimates the peak shear strength, but correctly estimates the residual shear strength. Comparing the field and laboratory undrained shear strength results, the field measurements of peak strength seem to be less reliable.

The sensitive soils from New Zealand are different than the sensitive soils of Canada and Norway in a few significant ways. The New Zealand soils originated as volcanic silts dominated by glass shards with some crystals. Their behaviour is more similar to silts as demonstrated by the Atterberg limits tests. Significant amounts of the original glass fragments have been weathered to form clay minerals. The Canadian and Norwegian soils are glacial derived sediments deposited in estuarine environments. They have seen little weathering post-deposition

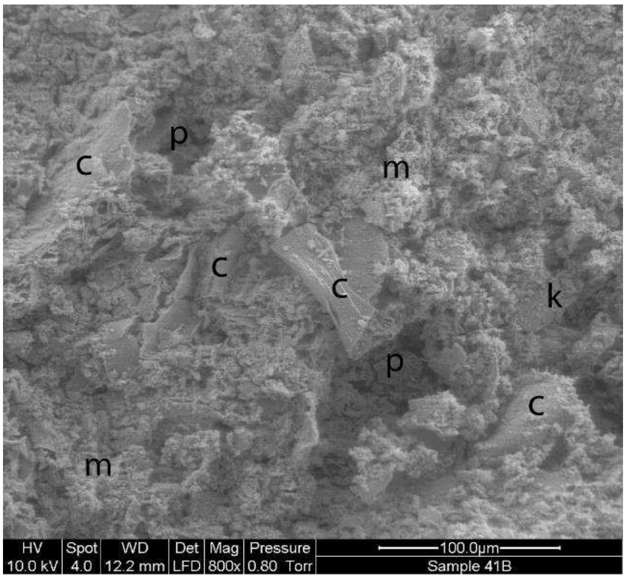


Figure 8. SEM photomicrograph of sample 41 from Pahoia. c - crystal grain, m - clay matrix, p - pore, k - kaolin microaggregate.

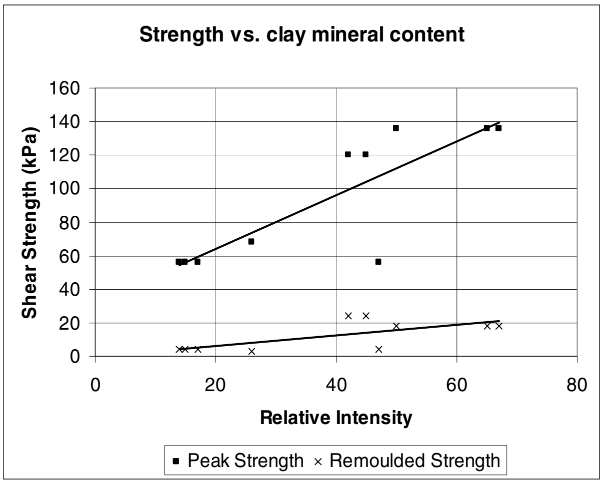


Figure 9. Relative intensity of 7A peak measured by XRD and shear strength measured by field shear vane

and behave as clays. There are a few important similarities. In both cases, the soils are relatively young and normally consolidated. In both cases, particle shape favoured deposition in a low-density, high-porosity state. This is likely one of the key parameters in the development of sensitivity in both cases.

Clay content also has a large effect on the geotechnical properties of these soils. Figure 9 shows the relationship between crystalline clay content (as relative intensity of the 7Å XRD peak) to the shear strength measured by the field shear vane. Both peak and remoulded shear strength increase with increasing clay content; however, the peak strength increases faster, leading to a greater sensitivity.

## 6 CONCLUSIONS

The field shear vane may not be an accurate method to measure shear strength of sensitive volcanic soils. Despite different origins, sensitive New Zealand, Canadian, and Norwegian soils share some common properties. These similarities are likely the most important properties responsible for the development of sensitivity.

## ACKNOWLEDGEMENTS

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