Geotechnical Offshore Seabed Tool (GOST): CPTu measurements and operations in New Zealand

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ABSTRACT: The Geotechnical Offshore Seabed Tool (GOST) was used in three field campaigns in on- and offshore areas in Tauranga, Bay of Plenty, New Zealand. Offshore measurements were performed along the main shipping channel in the Tauranga Harbor and onshore measurements were conducted at the locations of two landslides at Pyes Pa and Omokoroa. From each of these sites a sample static CPTu profile is described and reviewed. Additionally, a vibratory CPTu from the Pyes Pa landslide is presented. The CPTu results were used for subsurface sediments investigations at the tested locations.

1 INTRODUCTION

In Tauranga Harbor, New Zealand, recent interest in dredging operations to widen and deepen the shipping channel to accommodate larger vessels up to 7000 twenty foot equivalent units has provided the impetus to perform sediment stratigraphy and characterization of the area. Ongoing dredging operations have been undertaken since 1968 to improve navigation for shipping in the harbor (Healy *et al.* 1996). Observations of weathered volcanic ashes with high clay content and weathered ignimbrite in core samples taken for Port of Tauranga development projects imply that this sequence is widespread in the sub-surface stratigraphy of the harbor, especially along the dredged channel. Identification of ash layers before dredging was one of the most important issues in a project designed to predict any instability prior to dredging, and to identify measures to reduce turbidity during dredging and disposal. In addition, distribution of ignimbrite layers is an important factor for dredging as these layers are much harder to dredge compared with the ash layers and hence, require different dredging methods.

In the Tauranga basin, slope failures commonly occur after heavy rainfall events. Onshore low permeability volcanic ash layers act as a barrier to groundwater movement flowing excessive rainfall and hence prevent pore pressure dissipation. Accumulated rainfall above the ash layers boosts pore fluid pressures in the overlying material lowers shear strength and leads to slope failures. Two of the most recent slope failures occurred at Pyes Pa and Omokoroa; these failures caused loss or damage to public and private properties (Figure 1).

In a collaboration between the University of Bremen in Germany and the University of Waikato in New Zealand, *in-situ* measurements of sediment physical and mechanical properties were carried out with the use of a CPTu unit called GOST (Geotechnical Offshore Seabed Tool). The instrument design and modes of deployment are described in another paper prepared for this conference (see Jorat *et al*, this issue).

The offshore tests at the Tauranga Harbor were conducted from a barge where GOST was positioned and retrieved from the seafloor using a crane mounted on the barge with 5 ton lifting capacity. The barge was held in position with three anchors. The barge was positioned by a tug-boat provided from the Port of Tauranga Ltd.

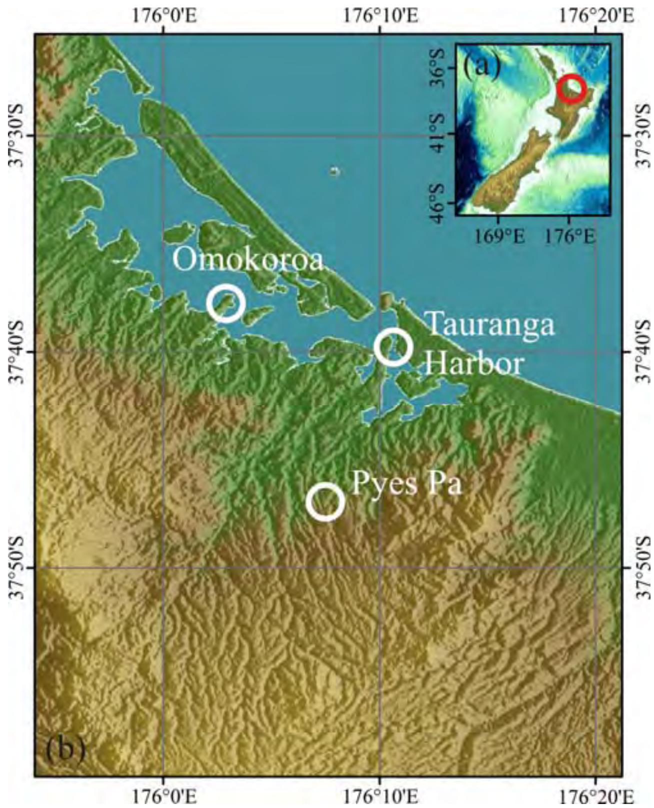
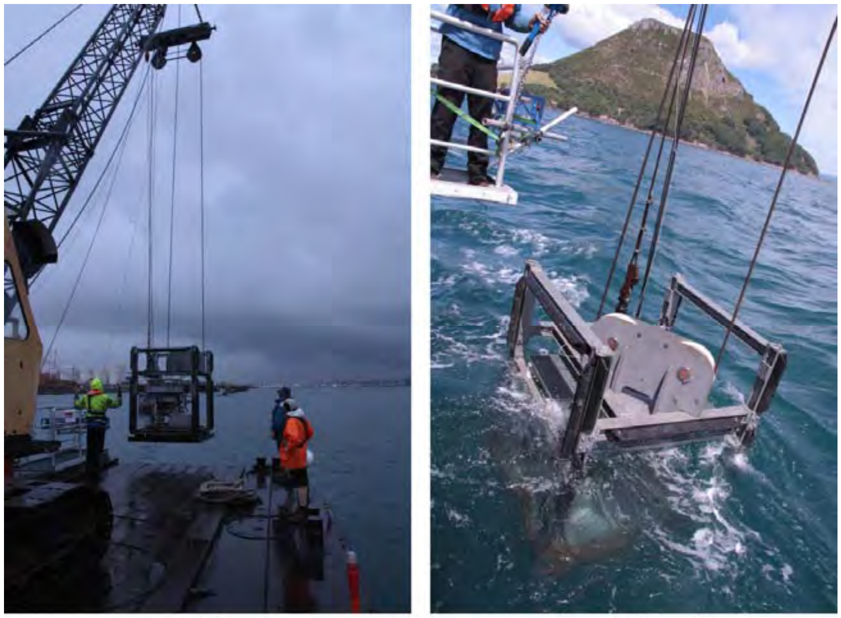


Figure 1. Map of (a) New Zealand and (b) CPTu field campaign sites in Bay of Plenty. Both maps are generated from Land Information New Zealand data.

During two weeks, 15 static CPTu, two vibratory CPTu, one remolding test and one dissipation test were conducted along the Tauranga Harbor (Figure 2) shipping channel. Of those, one static CPTu deployed in the dredged section of the harbor that is known as Stella Passage is presented in this paper.



(a) (b)

Figure 2 (a) & (b). GOST during deployments in Tauranga Harbor.

For onshore tests at the Pyes Pa and Omokoroa landslides, instruments were transported to the location and positioned by truck crane, and a mobile generator was used to provide power for the instruments. During two days, two static CPTu, two vibratory CPTu, two remolding tests and one dissipation test were conducted at both landslide locations (Figure 3). Of those, one static and vibratory CPTu performed at the Pyes Pa landslide and one static CPTu performed at the Omokoroa landslide are illustrated in this paper.

(a) (b)

Figure 3. GOST during deployments at (a) Pyes Pa and (b) Omokoroa.

The objectives of this paper are to:

(a) present CPTu traces for sub-surface investigations at Tauranga Harbor, the Pyes Pa landslide and the Omokoroa landslide and match identified layers with known geological sequences of the areas.

(b) compare geological sequences in Tauranga Harbor with the Omokoroa landslide by using static CPTu; and

(c) investigate the impact of vibration on sediments from different geological sequences at the Pyes Pa landslide by comparing static and vibratory CPTu.

2 RESULTS AND DISCUSSIONS

2.1 *Stella Passage, Tauranga Harbor*

Figure 4 represents a typical CPTu data-set, including tip resistance, sleeve friction, friction ratio and differential pore pressure data collected *in-situ* within Stella Passage, Tauranga Harbor. In addition, Soil Behavior Type (SBT) generated from CPTu results and the SBT chart from Robertson *et al.* (1986) was evaluated by the CLiq (2008) software program and has been added to the figure (Figure 4).

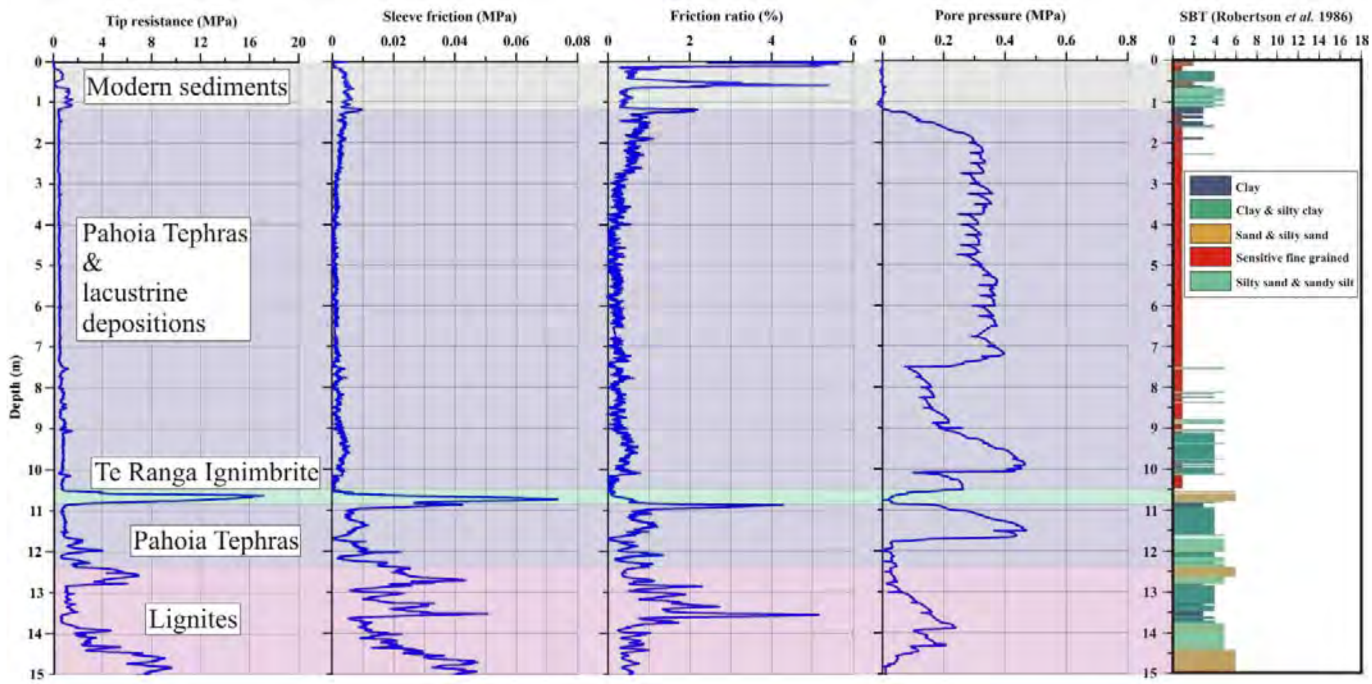


Figure 4. CPTu and soil behavior type results from Tauranga Harbor.

Elevated tip resistance and sleeve friction, very high friction ratio and zero differential pore water pressure values are the main characteristics of a shelly sand layer described by Davis and Healy (1993) as the upper lithofacies along Stella Passage within Tauranga Harbor. In the first 1.20 m of the soil profile, the presence of broken shells in marine sand sediments is indicated by a rapid increase of friction ratio values to more than 4 % (Figure 4).

SBT results from analysis of CPTu between 1.20 and 10.50 m of the profile indicates the existence of sensitive fine-grained layers. Very low values of tip resistance and sleeve friction, as well as a rapid increase in differential pore water pressure are the main CPTu characteristics of the layers indentified as sensitive layers in SBT graph. Observations of cores taken from Stella Passage indicate that below the shelly sand layer, a thick layer of pumiceous sands, silts and clays is deposited (Opus, 2011). This material is part of the Matua Subgroup, a complex sequence of primary and reworked pyroclastic materials (Briggs *et al.*, 1996). Within the Matua Subgroup are two finer-grained units: the Pahoia Tephras, a sequence of fine-grained pyroclastic that is extensively weathered to clay materials, and localized diatomaceous silts representing lacustrine deposition.

At about 12 m, sharp increases in tip resistance, sleeve friction, friction ratio and a decrease in differential pore water pressure is attributed to the presence of a pumiceous sand and gravel unit observed in Opus (2011) cores taken from the Stella Passage. This unit likely corresponds to the Te Ranga Ignimbrite described by Briggs *et al.* (1996). This is underlain by coarse lignite materials which show increasing tip resistance and sleeve friction and a decreasing pore water pressure response.

2.2 *Pyes Pa landslide*

In this section, static and vibratory CPTu results performed at the Pyes Pa landslide are reviewed. Figure 5 shows static and vibratory tip resistance and pore water pressure. Comparisons between static and vibratory CPTu results exhibit the impact of *in-situ* dynamic loading on the sediments. The CPTu field campaign at the Pyes Pa landslide was previously discussed by Jorat *et al.* (2014).

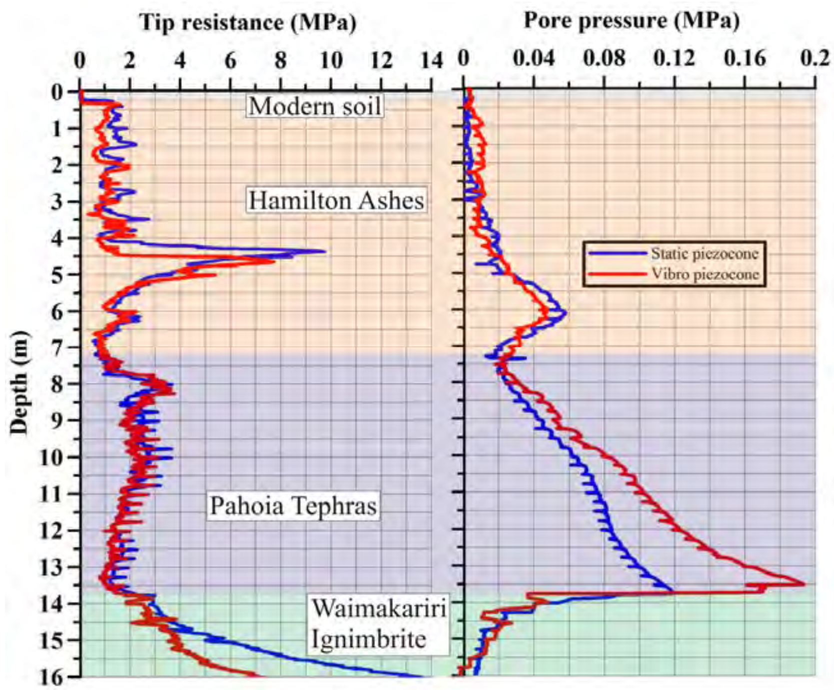


Figure 5. Comparisons of static and vibratory CPTu test results (after Jorat *et al.* 2014).

Jorat *et al.* (2014) suggest that the first 7 m of the profile consists of an ash sequence that overlies a paleosol layer. Considering the general stratigraphy of the Tauranga region proposed by Briggs *et al.* (1996), the ash layer is likely to be Rotoehu Ash or the Hamilton Ashes sequence. Jorat *et al.* (2014) also observed an apparently clayey layer from 7 to 13.70 m that has similar tip resistance and differential pore water pressure signatures to the Pahoia Tephra identified in the Tauranga Harbor CPTu results (Figure 5). From the depth of 13.70 to 16 m depth, a poorly welded ignimbrite, probably Waimakariri Ignimbrite, was observed (Jorat *et al.* 2014).

Static and vibratory CPTu do not show obvious differences between the tephra layers except between 4 and 4.50 m (Figure 5). As the deposition of the materials is not always horizontal, 1 m of horizontal distance between soundings can cause some variation in CPTu profiles that is inferred to be the reason for large differences between static and vibratory tip resistance between 4 and 4.50 m. Within the ignimbrite layer, vibratory tip resistance decreases consistently, which is attributed to the reduction of penetration resistance under the effect of vibration.

Static and vibratory pore pressures are consistent with each other within the modern soil, Hamilton Ashes and Waimakariri Ignimbrite layers (Figure 5). However, in the Pahoia Tephra sequence, pore pressure in vibratory mode increases consistently compared with pore pressure in static mode. The increase in pore water pressure directly leads to a decrease in effective stress that may lead to slope failure. The largest increase in pore water pressures under the effect of vibration was recorded at a depth of 13.70 m, which is therefore the depth most vulnerable to dynamic loading.

2.3 *Omokoroa landslide*

CPTu measurement was undertaken immediately behind the scarp of the landslide at Omokoroa. Figure 6 shows results of tip resistance, sleeve friction, friction ratio, differential pore water pressure and SBT. Static CPTu tip resistance and pore water pressure at this landslide were shown and described by Moon *et al.* (2013) and the results are reviewed here.

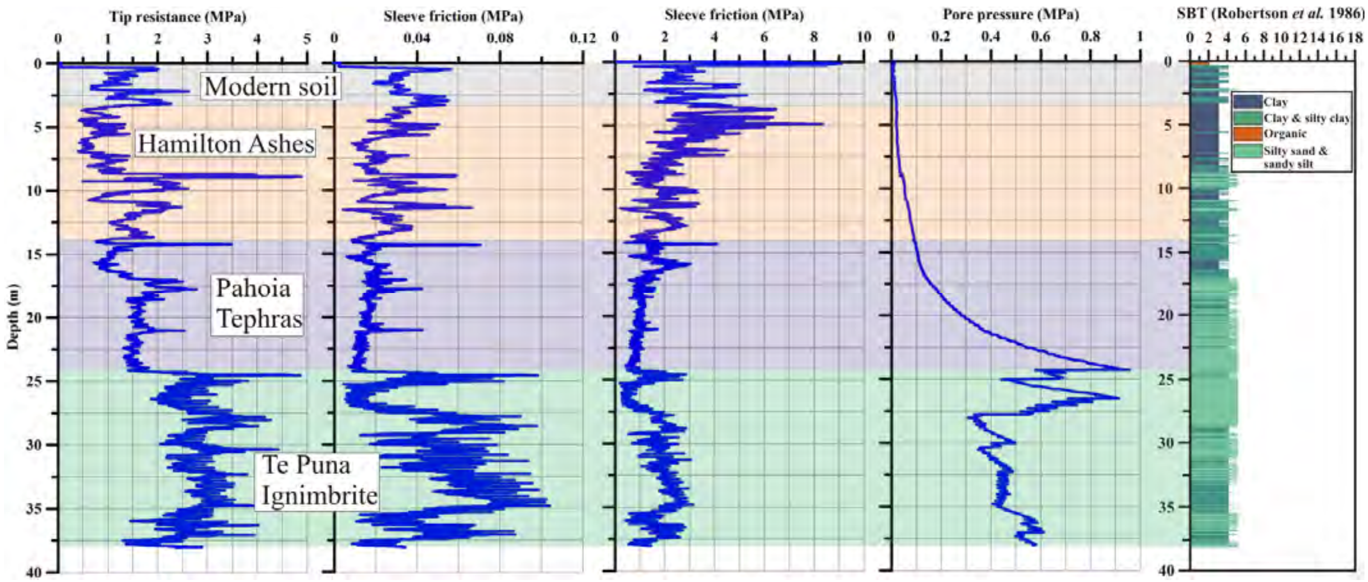


Figure 6. CPTu and soil behavior type results from the Omokoroa landslide. Tip resistance and pore pressure are after Moon *et al.* (2013).

The stratigraphic sequence along the first 24 m of sediments from top to bottom consist of Pleistocene and Holocene materials considered as modern soil, Rotoehu Ash, Hamilton Ashes and Pahoia Tephra (Moon *et al.* 2013). Low values of tip resistance and sleeve friction and elevated pore water pressure were recorded within these pyroclastic sequences (Figure 6). However, the SBT units corresponding to these sequences at the Omokora landslide are different from the Tauranga Harbor SBT units. The Hamilton Ashes sequence which is present at the Omokoroa landslide is not preserved at the site of the CPTu at Tauranga Harbor. Tip resistance and sleeve friction values within the Pahoia Tephra sequence at the Omokoroa landslide are slightly higher than the ones in Stella Passage. However, the rapid increase in pore water pressure within the tephra layer is similar to the signature of the tephra layer located in Stella Passage. According to Moon *et al.* (2013), the Pahoia Tephra is the sequence associated with the sensitive soil failures in the Tauranga region. Te Puna Ignimbrite lies below the Pahoia Tephra sequence at the landslide location (Moon *et al.* 2013) that is different from the type of ignimbrite present at the site of the CPTu at Turanga Harbor. Increases in tip resistance and sleeve friction and decrease in pore water pressure in the CPTu results below the depth of 24 m is associated with the presence of Te Puna Ignimbrite.

3 CONCLUSIONS

GOST was shipped to New Zealand and a series of tests were performed in Stella Passage, Tauranga Harbor, and two nearby landslides at Pyes Pa and Omokoroa. In Stella Passage, four main sequences consisting of modern sediments, Pahoia Tephras and lacustrine deposition, ignimbrite and lignite materials and in the Pyes Pa landslide and the Omokoroa landslide, four main sequences consisting of modern soil, Hamilton Ashes, Pahoias Tephra and ignimbrite are recognized and matched with the known geological sequences.

Very low tip resistance and rapid increase of differential pore water pressure are the CPTu signatures of the ash and the tephra layers found at the Tauranga Harbor and the Omokoroa landslide. Tip resistance of the ash and the tephra layers at the Tauranga Harbor is significantly lower than the ones located at the Omokoroa landslides due to greater pumice content in Stella Passage.

At the Pyes Pa landslide site, vibration increased values of pore water pressure within the tephra layer, which resulted in a reduction of effective stresses. The results showed the vulnerability of the layer to loss of strength under dynamic loading conditions.

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