Pore pressure response during tube sampling in gold tailings

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Abstract. Capturing the in-situ state of mine tailings is important in determining its behaviour under loading for evaluating the risk of failure of tailings dams. Obtaining a high-quality undisturbed sample through tube sampling is thus of great value to the responsible engineer. However, the sampling process itself disturbs the soil and changes its state. Since soil behaviour is driven by effective stress, one method to evaluate the disturbance induced during tube sampling is to monitor the soil's positive and negative pore water pressure response during the process. A laboratory study was conducted where tailings samples were prepared at a controlled void ratio and subsequently saturated with water. Tube samplers of different diameters were driven into the material and extracted by means of an electric actuator during which internal sample pore pressures were monitored using tensiometers. The material experienced significant instantaneous contractive and dilative tendencies during insertion. Instantaneous negative responses during extraction of the tube samplers were also measured. It was found that the largest tube sampler (100mm diameter) performed best in the study.

1 Introduction

Soil sampling plays a vital role in geotechnical engineering. It allows engineers to extract, investigate and test soils to better understand the subsurface conditions at a particular location and measure the relevant engineering parameters for design by means of laboratory testing.

Soil sampling poses a high potential for the sample to become disturbed in various ways, which in turn could give inaccurate representation on the desired soil properties relevant to undisturbed sampling.

Thin-walled tube sampling is a valuable method for withdrawing relatively cohesive and stiff to soft soil samples. Tube sampling's primary aim is to extract and preserve a sample whilst minimising disturbances of it.

Disturbances caused by tube sampling often occur within soil samples over long durations of time as the sample is transported or handled. The objective of tube sampling would be to retain the same effective stress that the sample experienced in-situ. As the total stress is changed in the sampled material by removing it from the ground, it is thus ideal to keep the sample intact as this will preserve the state of the material. The most beneficial case would thus be to generate negative pore pressures in the sample equal to the total stress that was released from the material during extraction.

It is, therefore, of value to study this mechanism to better understand the pore pressure regime during the sampling procedure. By identifying how much total stress was released from sampling and measuring the suction generated from sampling, sample quality assessment may be quantifiable by means of tracking the changes in effective stress and in void ratio.

2 Background

2.1 Ground Investigations

An adequate ground investigation is the first step in approaching most geotechnical problems [1] and is essential in executing most civil engineering projects [2]. Investigations aim to obtain sufficient subsurface profile information to enable a safe and economical design and avoid any difficulties during construction, as well as throughout the lifecycle of the project [3]. Before any in-situ testing or sample collection can be initiated, the soil must be excavated or drilled to the depth of interest. There are various methods that could be utilised and the most appropriate is selected depending on the investigation's aims. Upon completion of ground investigations, engineers can use the information obtained and apply design calculations to make the appropriate recommendations [1].

2.2 Soil Sampling

The objective of soil sampling is to obtain samples with the least amount of disturbance [1] so that accurate laboratory tests can be conducted to determine the required soil properties [4].

Sample disturbance according to [5] can be induced during sampling, transportation, or during storage and can take on many forms, including the following:

1. Change in stress condition.
2. Mechanical disruption of the soil structure.
3. Changes in water content and porosity.
4. Mixing and segregation of soil constituents.

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While performing sampling, the goal should be to eliminate factor 4 above while aiming to minimise factors 1 to 3 as much as possible [1]. Soil sampling can be categorised into two categories, *i.e.,* disturbed and undisturbed sampling.

2.2.1 Disturbed sampling

A disturbed sample is a soil sample with a similar particle size distribution to an in-situ soil sample. However, the soil fabric has either been significantly damaged or destroyed by excavations or borehole drilling, and water contents may often differ [2].

Disturbed samples are primarily used according to [3] for:

a) Visual identification/description of soil layers.
b) Classification tests (grain size distribution, water content and specific gravity and Atterberg limits).
c) Compaction tests.

2.2.2 Undisturbed sampling

Undisturbed sampling aims to extract a representative soil sample where the in-situ structure, water content and void ratio are preserved as far as practically possible [6]. Undisturbed samples are generally extracted by means of careful block sampling or tube sampling from the bottom of undisturbed boreholes or trial pits [2].

According to [3] undisturbed samples, are primarily used for:

a) Laboratory shear strength tests
b) Laboratory consolidation/compressibility tests

It is practically impossible to obtain a perfectly undisturbed soil sample, regardless of the effort that went into the ground investigation and the type of sampling method used [7].

2.2.3 Sample quality classes

Soil samples can exhibit different degrees of disturbance depending on the sampler types and methods used. This degree of disturbance can be categorised using various standards such as described in [8] that classifies soil quality into five different classes, namely class 1 to class 5, where:

- Class 1 is of the highest quality.
- Class 5 is only valid when the objective is essentially visual identification of the soil type.
- Class 1 and 2 require the soil samples to be undisturbed.
- Unlike classes 1 and 2, classes 3 to 5 can be of disturbed soil.

2.3 Thin-walled tube sampler

Various methods of obtaining disturbed or undisturbed samples can be applied in ground investigations. The use of the thin-walled tube sampler, also known as the Shelby tube sampler, is a useful method for withdrawing quality undisturbed soil samples [2]. The thin-walled tube sampler comprises a steel tube possessing a sharp cutting edge and no inside clearances. It is noted that thin-walled samplers do not have a separate cutting shoe.

Tubes are often carefully driven manually when used in trial pits and shallow boreholes but can also be hydraulically pressed and pulled at carefully controlled rates to avoid tube damage [9] or plugging when applied pressures exceed the soil-bearing capacity [1].

After insertion, samplers are extracted from the soil and then wrapped and sealed using molten wax or O-ring packers to prevent moisture loss [3] before they are taken to a laboratory for extrusion and potentially complex soil testing.

2.4 Pore pressures in saturated conditions

An important consideration in fully saturated soil conditions is the equalisation of present pore water pressures when the sample has been retrieved from the ground. Although this may be relevant in conventional soil mechanics, the disturbances induced by the tube sampling procedure tend to induce an unsaturated state while the soil is being sampled, as air could potentially be forced into the soil mass from the compressing air pocket at the top of the sampler tube. During the extraction process, the development of significant negative pore pressures is present, implying that two different pore pressure regimes are exerted on the sample as the soil is sampled. These pore pressures developed during sampling may dissipate to a stable condition or be held with a vacuum pump at a constant negative excess pressure.

Since water is considered incompressible, any increase in total stress within undrained, fully saturated conditions is equal to the induced pore pressures [2] within the soil. An alternative approach is to assume the generated pore pressures equal to the change in total vertical stress.

Depending on drainage, excess pore water pressures generated within soil will reduce with time during the process of dissipation. Similarly, any unloading of total vertical stresses during sampling will cause an initial decrease in excess pore pressures before reaching stable conditions.

2.5 Tensiometers

Use of tensiometers is the simplest and most common instrument for directly measuring both positive and negative pore water pressures [10]. Tensiometers operate by allowing pore water to come into equilibrium with a reference pressure sensor through a small water reservoir that is connected to a permeable ceramic filter element. The saturated ceramic filter element is placed in contact with the soil and the exchange of water between the soil pores and the pressure sensor allows for negative or positive pore pressures to be directly measured.

Standard tensiometers, however, are limited in the sense of only being able to measure suctions up to the range of 70-85 kPa due to the influence of cavitation and dependent on the height above sea level [11][12].

2.6 Evaluating the performance of tube sampling

[13] investigated the mechanism of sample disturbance caused by tube insertion on Toyoura sands and found that at lower relative densities, the pore water pressure response over a time period of approximately 32 seconds showed to be positive in magnitude. However, at high relative densities, negative pore pressures are induced. This occurs due to respectively the density dependent contractive and dilative behaviour of the material under shear. Very few experimental studies have been performed on thin-walled tube sampling and its effects on pore pressure behaviour during the sampling actions.

3 Experimental Setup

3.1 Gold Tailings Material

This study focused on tube sampling in gold tailings. The tailings material used in the experiments was obtained on the outer wall of an active gold tailings storage facility (TSF) near Johannesburg, South Africa. The dam is an upstream constructed facility.

The gold tailings could be described as a moist, grey, very soft, sandy silt with a uniform particle size distribution, seen in Fig. 1.

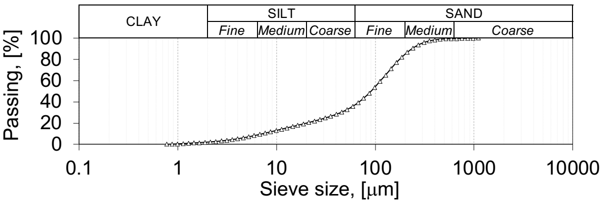

Fig. 1. Particle Size Distribution Curve.

Selected properties of the collected gold tailings are presented in Table 1. These represent typical values for South African gold tailings.

Table 1. Selected gold tailings properties.

Parameter	Value	Test Method
Median grain size, d_{50}	0.063 mm	ISO 13320 :2020
Maximum void ratio, e_{max}	1.57	ASTM D4252-00
Minimum void ratio, e_{min}	0.47	ASTM D4253-16
Specific gravity, G_s	2.74	ASTM D4550-14
Soil classification	(MS) Non-plastic sandy silt	ASTM D2487-11

A median particle size of 0.063 mm was determined from the grading curved which was determined using laser diffraction in accordance with [14]. A specific gravity of 2.74 was determined using the gas pycnometer method described in [15]. The void ratios were determined according to [16] and [17], respectively. A minimum void ratio of 0.47 was determined using Test Method 1A from [18]. Test Methods B and C were followed to obtain the maximum void ratio of 1.57. The material classifies as a non-plastic sandy silt (MS) according to [19].

3.2 Model container

The study utilised a centrifuge strongbox with internal dimensions 600x400x400 mm as model container, as seen in Fig. 2. The box incorporated a water supply with a water table set at the surface by means of a standpipe. Water was introduced at the bottom of the box through a sand layer separated from the tailings by a geofabric. The material was moist compacted in five layers (w = 9%), each 80mm in depth. A void ratio of 0.85 was targeted.

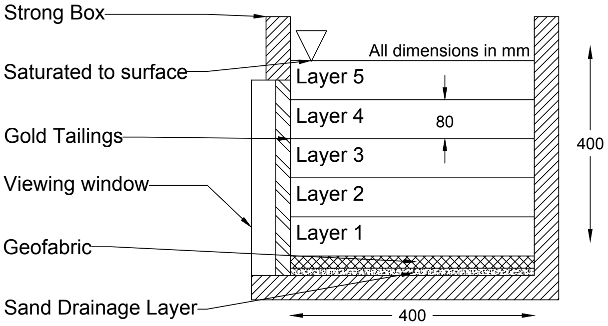

Fig. 2. Model container (strongbox).

3.3 Tensiometers

High capacity tensiometers (HCTs) were used to measure the pore water pressure responses during the study. The HCTs have the ability to measure both positive and negative pore pressures between the ranges of approximately - 500 to 500 kPa. A single tensiometer is illustrated schematically in Fig. 3.

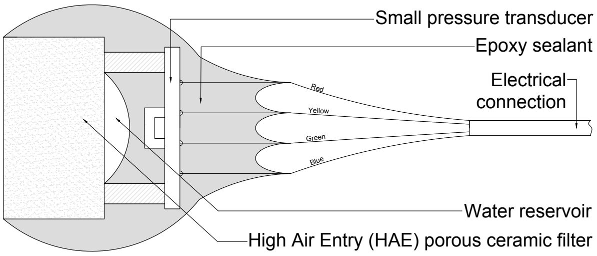

Fig. 3. High Capacity Tensiometer.

After saturation and calibration, the tensiometers were installed at locations indicated in Fig. 4, which were decided upon such that tensiometers would be buried at two control depths, namely 150mm and 225mm, along the vertical centreline of the sample.

Additional tensiometers were placed in the material surrounding the tube to observe the generation and dissipation of pore pressures adjacent to the sampling zone. These locations are measured at 32.5mm and 62.5mm from the tube sampler's perimeter.

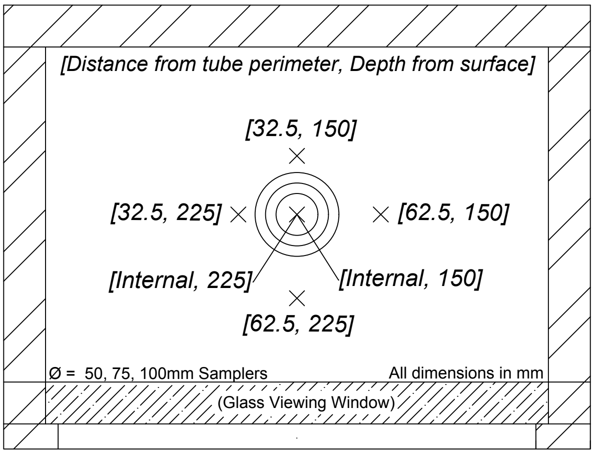

Fig. 4. Tensiometer placement layout in plan view.

Prior to tensiometers installation, the model was flooded to saturate the material. Holes were carefully augured to place the tensiometers. PVC tubes were used to case the holes and prevent collapse before each tensiometer's installation. A moist tamped backfilling procedure was followed to complete the installation. The tensiometers were monitored during the installation to ensure that they did not cavitate due to dry-out.

3.4 Development of the tube samplers

Sampler diameters of 50, 75 and 100 mm diameter were utilised in the study. Custom manufactured thin-walled tube samplers and sampler end-caps were produced, with provision to incorporate the tensiometer leads.

During insertion of the sampler, the leads were free to slide through the sampler cap, which allowed the tensiometers to remain at the specified installation depths.

During extraction of the sampler, the leads were secured with a quick setting glue to air-seal the system and to allow the tensiometers to remain within the sample during removal.

A vacuum line was also provided to allow a partial vacuum to be applied to the top of the sample in an attempt at retaining the soft material which generally tended to slide out of the sample tube upon extraction of the sampler from the ground. A typical sampler geometry is presented in Fig. 5.

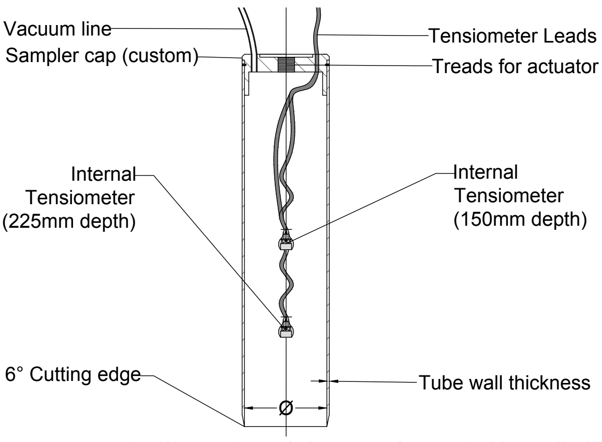

Fig. 5. Generic illustration of the manufactured thin-walled tube samplers.

3.5 Load cell and actuator

A linear actuator and a 24V power supply were used to control the movement of the tube sampler. An HBM U9C load cell was introduced to measure penetration resistances during insertion and extraction. The configuration of the components linking the actuator to the sample cap are presented in Fig. 6.

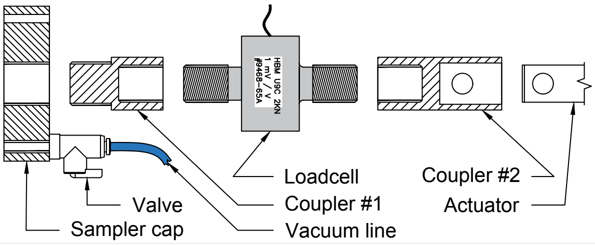

Fig. 6. Assembly diagram of the experiment showing the configuration of actuator and loadcell.

4 Results and Discussion

4.1 Tube sampling procedure

The pore pressure response during the tube sampling procedure, measured by the internally placed tensiometers, can be seen in Fig. 7. The main responses as denoted on the figure show the insertion stage, a period of dissipation, the vacuum application stage and subsequent sample extraction from the model.

The dissipation stage allowed for excess pore pressures generated during sampling process to reach equilibrium with the material in the model.

The vacuum stage was introduced in an attempt to retain the soft material inside the tube, such that a usable volume could be removed from the model.

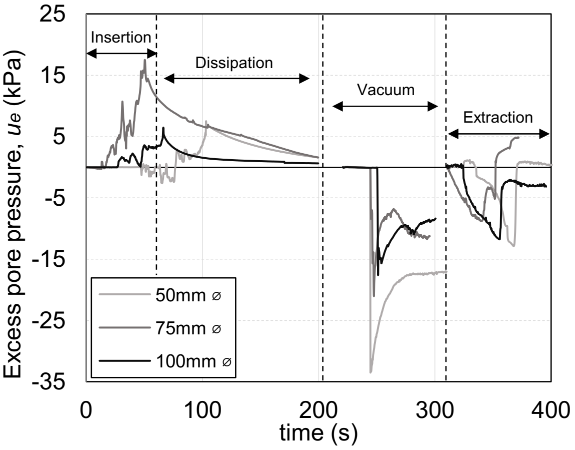

Fig. 7. Pore pressure response during sampling procedure.

During the sampling insertion stage, significant positive and increasing excess pore pressures were generated as the sampler was driven within the tailing's material.

During the sampling extraction stage, a clear negative pore pressure regime was generated in the sampled material.

The positive and negative excess pore pressures generated were of similar orders of magnitude.

4.2 Soil element response during sampling

Figures 8 to 10 present the pore pressures measured by the internal tensiometer embedded at 150mm depth as a result of the approaching sampler tube cutting edge for the three sample diameters investigated. The vertical distance from the tensiometer is normalised by sampler diameter, (*D*).

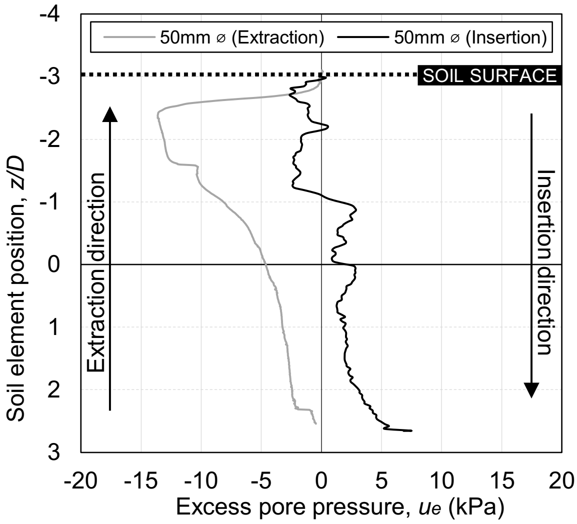

Fig. 8. Internal tensiometer response for 50mm ⌀.

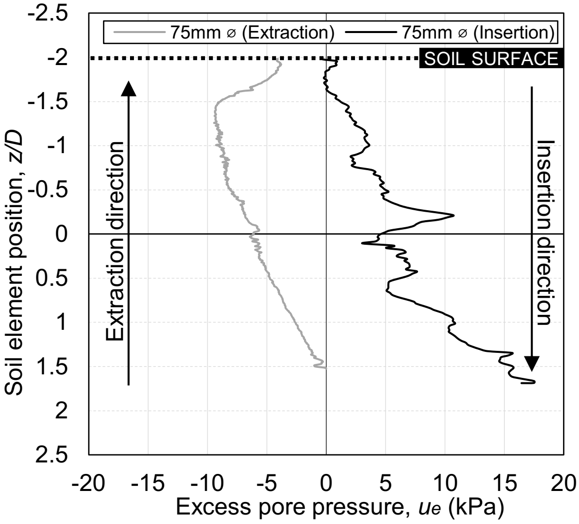

Fig. 9. Internal tensiometer response for 75mm ⌀.

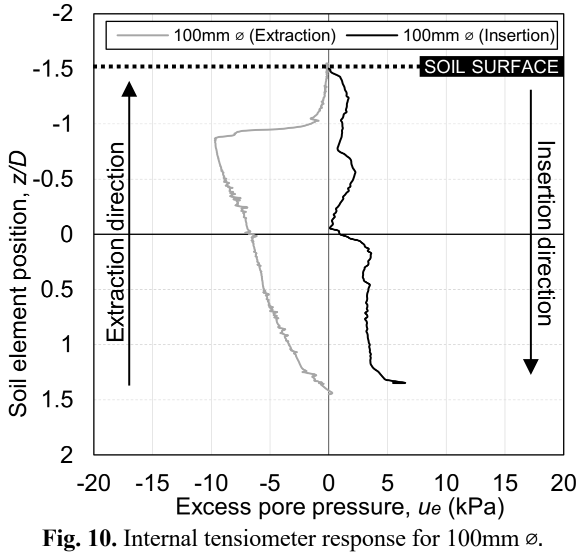

Fig. 10. Internal tensiometer response for 100mm ⌀.

The trend, as the sampler tube cutting edge approached, illustrates a general tendency of increasing pore pressures, while a gradual reduction in pore pressures is induced as the cutting edge reached close proximity of the buried tensiometers. A typical dilative soil response due to sampling. Thereafter, the pore pressure suddenly increased with further penetration of the cutting edge. The controlled extractions of the sampler tubes were accompanied by a dominating negative pore pressure regime that was monitored for all sampler diameters. The results show that the negative excess pore pressures within the samples rapidly returned to zero as the cutting edge approached the soil surface. This is likely a case of air being allowed to enter the sample mass from the bottom of the tube. In Fig. 8. a relatively small gradual reduction of excess pore pressures was observed from z/D = 1 above the respective measurement location, a relatively sharp reduction from 0.2 z/D in Fig. 9. and a gradual reduction from 0.5 z/D in Fig. 10. After the cutting edge of the sampler has passed the depth of embedment of the tensiometer, positive pore pressures seemed to be generated in the soil.

Given some scatter, there is no apparent distinction between the pore pressures developed during the insertion of the sampler for the varying diameters tested. However, it is evident that the magnitude of the negative pore pressures experienced in the soil during extraction of the tubes generally exceeded the magnitude of the positive pore pressures.

The effect of the applied vacuum allowed sample retention for all tests and is thus advantageous for sampling soft material such as the saturated tailings.

5 Discussion

During undisturbed sampling, the ideal is to extract the sample while preserving its original effective stress. This should prevent changes in the void ratio and hence state of the sample, which is important since soil behaviour upon shear is highly state-dependent. Driving a thin-walled sampler into the ground is likely to slightly raise the stress level and, given undrained or partially drained conditions, be accompanied by some positive pore pressure. Also, due to the shearing action of the penetrating sampler, shearing related dilation or contraction can also be expected, which is complicated by the heterogeneity of typical tailings deposits. All of the above result in complex stress changes during sampler penetration as demonstrated by the pore pressure measurements during sampling presented above.

In this study the magnitude of pore pressures generated during sampler penetration were generally smaller than the negative pore pressures generated during extraction. The positive pore pressure was likely comparable to the total stress changes associated with the insertion of the samplers, which were in turn roughly comparable to the original total stress at the measurement location (estimated at 2 to 3kPa at 150mm depth). This means that sampler penetration was likely to leave the effective stress relatively unchanged. However, the extraction of the samples was accompanied by negative pore pressures significantly exceeding the likely release in total stress associated with extraction of the samples from the ground. As partial drainage during sample extraction is unavoidable, the positive effective stress generated from the induced suctions was likely to reduce the sample void ratio. It is therefore believed that a reduction in void ratio can generally be expected during tube sampling of tailings under conditions similar to those in this study. This means that the state parameter will be under estimated, resulting in potentially non-conservative conclusions regarding liquefaction potential.

6 Conclusion

The controlled insertion and extraction of the soil sampler tubes, accompanied by the use of tensiometers, allowed pore pressure changes to be studied throughout the sampling procedure. The study showed both positive and negative pore pressure regimes experienced by the soil mass due to tube sampling. The main conclusions of the study are as follows:

1) During both insertion and extraction of a thin-walled tube sampler into tailings, significant changes may occur in the pore pressure regime within the sample.
2) The magnitude of positive pore pressures generated during sampler insertion was smaller than that of the negative pore pressure generated during sampler extraction. It appears that disturbances during sampler insertion are smaller than those associated with extraction.
3) The significant negative pore pressures developed during the extraction procedure under conditions of partial drainage is likely to result in a reduction in void ratio upon sampling so that the in situ void ratio is under-measured, with potentially non-conservative consequence when estimating the state parameter.
4) The use of an applied vacuum during the extraction of the tube sampler greatly assisted in retention of the sample mass, even if it the material is soft and saturated in nature.
5) Larger diameter sample tubes cause smaller disturbances than small diameter tubes during sampling.

7 References

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