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# Consolidation and strength development of soft mud deposits by horizontal drainage

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## Introduction

The management of fine sediments will be increasingly important. Large amounts of mobilised sediments will progressively be used for nature building projects. Existing literature extensively covers the building properties of traditional materials, yet natural ones, because of their diverse properties, present a greater challenge. In this paper, this challenge is addressed by determining the strength behaviour of fresh mud through consolidation experiments with horizontal drainage, performed in cylindrical columns.

A series of experiments, which determine the consolidation and strength development of fresh mud deposits from Markermeer Lake (the Netherlands), is described. This novel approach mimics land and crust formation with soft soils. The influence of crust formation and sediment variability on the consolidation process is carefully studied, as well as the physical-chemical interactions. The results provide engineering rules for wetland creation and contribute to the understanding of the dominant mechanisms for soil formation from soft sediments.

## Methods

Consolidation experiments are conducted in 1.3m high PMMA transparent columns, of which the inner diameter is 10.0cm. To allow horizontal drainage, a porous pipe equipped with a filter only permeable for water is placed in the centre of the column and the water is slowly pumped out.

All columns are equipped with an impermeable base. On their walls, a scale bar allows the measurement of the consolidation development. The settlement of the water-mud interface, and the subsequent wet-dry and dry mud-air interfaces, are monitored by video. In addition, ten pore water pressure ports are installed at intervals of 5.0cm each, starting at 5.0cm from the base. An extra reference pressure port, which is always located above the sediment, is placed at 1.1m from the bottom. All the entries are provided with a Vyon plastic filter to prevent sediment leaking. This method was previously used by Bowden (1988), Merckelbach (2000) and Te Slaa et al. (2013). Every pressure port is connected to its pressure transducer, which is connected to a variable water table for calibration. The accuracy of the pore water pressure values is 1mm water head or 10 Pa, as determined by calibration.

The bulk density is measured using electrical conductivity. This is done via a Conductivity Concentration Meter (CCM). All columns have 10 conductivity probes situated at 5, 15, 20, 25, 30, 35, 40, 45, 50 and 65cm from the base, as shown in Fig. 1. The top probe is placed at a higher level as a reference magnitude in the overlying clear water. Each double platinum electrode probe, 1cm vertically spaced, is connected to a port. The probes are aligned with the wall curvature to reduce their influence on the deposition process.

Since conductivity measurements are sensitive to temperature fluctuations, and to reduce algae formation, the columns are placed in a climate room without light. Nevertheless, small temperature fluctuations are still possible. For the purpose of correcting temperature fluctuations, the temperature inside the columns is determined with a 50cm long probe with a resolution of  $\pm 0.1^\circ\text{C}$ .

At the same time, a parallel non-drained series of experiments is performed utilizing columns also equipped with pressure ports, but with a segmented lower part (see Fig. 1). The aim of this setup is to obtain different sections of the column, which are used to take samples for further geochemical analysis and submitted to the shear vane test. Thus, we acquire, for example, the strength profiles of the mud bed and the changes experienced by transformation of sedimentary organic matter from the starting point of the experiment. With the aim of estimating the evolution of the proportion of

components with different thermal stability, the Rock-Eval pyrolysis (Hetényi *et al.*, 2005) is applied at different phases of the consolidation process. The redox potential is also measured.

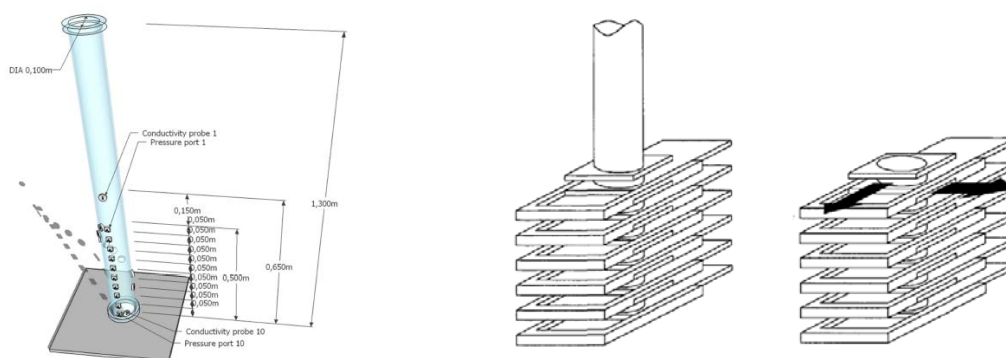


Fig. 1. On the left, the original columns adapted to get horizontal (courtesy of Steven te Slaa). On the right, the segmented columns used in the second series (Merckelbach, 2000).

The interaction between clay minerals and organic matter plays a decisive role at the consolidation process. Thus, the sediment is also characterised in detail before starting both series of experiments and an X-Ray diffraction analysis is performed to characterize the mineralogy of the clay as well as other fine-grained minerals.

An environmental scanning electron microscope (ESEM) is used to analyse two different mud samples. Humidities between 0% and 99% are applied for prolonged periods of time, while observing the changes in microstructure. In this way, the fabric of the clay can be studied in its most natural state (Cheng *et al.*, 2004).

The particle size distribution is first determined for an untreated sample using laser diffraction with a Malvern particle sizer. We observe that, according to the lithological classification, the type of sediment studied is in the range of silt. Therefore, the sample is pretreated to allow the dispersion of primary particles. The cementing materials are removed; organic matter by  $H_2O_2$  and carbonates by HCl. As a result, the clay distribution of the individual particles is obtained.

## Conclusions

With the experiments performed, the difference in consolidation behaviour is studied with and without horizontal drainage. Moreover, crust formation and how this crust affects the chemistry in the mud is measured. The Rock-Eval analysis reveals relatively high contents of organic matter and the ESEM yields insight into the presence of clay minerals versus other fine-grained particles within the clay and silt fraction. We also confirm that the organic matter material consists of humic substances, mainly fulvic acids.

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