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Determination of consolidation parameters of dredging and industrial waste sludge

La détermination des paramètres de consolidation des matériaux de dragage et de boues industrielles

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ABSTRACT

The paper presents the laboratory setup and some preliminary results of large strain consolidation testing on several types of dredging and industrial waste sludge. The tests are performed in the framework of a larger research project – funded within the Flemish Environmental Technology Platform (MIP) - investigating the impact of additives, specifically coagulants and flocculants, on the consolidation behaviour of mineral sludges..

Large strain consolidation parameters are determined using an adapted version of the well-known seepage consolidation test setup (Imai 1979). Interpretation of the test results is based on an iterative calculation using large strain consolidation theory as presented by Abu-Heyleh (1992). This procedure should allow an optimisation of type, concentration and application method of additives for a specific material.

RÉSUMÉ

La contribution traite le développement des essais de labo adaptés et les résultats préliminaires des essais de consolidation – grande déformation, exécutés sur des échantillons reconstitués partant des différents matériaux de dragage et de boues industrielles. Ces essais ont été réalisés dans le cadre d'un programme de recherche, supportés par la direction MIP de la Flandre, qui a pour but primordial la détermination de l'influence du traitement de ces matériaux industrielles et minérales, sur le comportement de consolidation de ces boues. Le traitement se fait par des coagulants et floculats spécifiques.

Les paramètres qui règnent le comportement de la consolidation – grande déformation - ont été déterminés ici partant d'un type d'essai adapté selon le principe de l'essai de consolidation – courant de filtration (Imai 1979). L'interprétation des résultats des essais a été basée sur l'approche d'un calcul itératif à partir de la théorie de la consolidation-grande déformation selon Abu-Heyleh (1992). Cette technique devrait nous permettre d'optimiser le type, la concentration et la méthode d'application de ces additifs pour chaque matériau de dragage et de boue industrielle sélectionné dans ce programme de recherche.

Keywords : large strain consolidation, tailings, SIC test, flocculant

1 INTRODUCTION

The storage of tailings and mineral slurries from industrial activity or dredging becomes increasingly problematic in heavily populated areas like Flanders.

There is therefore a growing interest from industry in methods to optimize the storage facilities. In this framework, the authors are involved in a running research project funded by the Flemish Environmental Technology Platform (MIP) which aims at adapting the behaviour of mineral slurries through the use of additives. The aim is quite broad as it looks at both geotechnical characteristics of the material and the aspect of pollutant transport. For this reason, a large number of parties are involved in the project : 5 research institutes, 8 companies and 2 public organisations.

The geotechnical research, which is the subject of this paper, will focus on methods to increase the disposal capacity of existing storage areas by treating the slurry material (both ex situ and in situ) using coagulants and/or flocculants.

Currently, flocculants are already commonly used by the (dredging) industry to improve dewatering of sludges and tailings. However, the choice of type and concentration of the additives is based on number of index tests which are doubtful to say the least and are moreover focussing on the behaviour of the material at very low density, so relevant to its sedimentation behaviour rather than its consolidation behaviour.

It is the aim of the authors to develop testing protocols and the relevant laboratory testing equipment to allow a real optimisation of the type and concentration of the additive based on the relevant parameters. The latter would depend on the desired behaviour of the material: fast initial dewatering at low density, overall higher permeability at higher stress levels, fast development of shear strength…

2 STRATEGY

As the main criterion for choosing the optimum additive is linked to the consolidation behaviour of the material, samples will be tested to determine the large strain consolidation parameters.

In a first part of the project, we assume that the mineral material is at very low density and therefore does not exhibit any structure, which would be equivalent to the situation of in-line (ex situ) mixing of the additive with the material.

In further phases of the project, we would also consider mixing with samples which already exhibit structure and study the impact of the mixing equipment on the final result. This is not discussed in this paper.

As we consider the situation of slurries (very high water content) it is necessary to get the non-linear permeability and compressibility functions for each material over a large range of stress levels. Determining large strain consolidation parameters could be done in several ways, using a combination of column tests, CRS, standard oedometer and flexible wall permeability tests. It was decided that an adapted SIC setup (seepage induced

consolidation) would have the most advantages: it is well-suited for testing at low stress levels and allows getting both the compressibility and permeability functions from one single test.

With this setup, different mixtures will be tested which would allow determining the impact of additives on the large strain behaviour and possibly optimising type and concentration of an additive.

Parallel to these tests, several experiments will be conducted to determine the impact of the additive on the development of shear strength in the material.

3 EXPERIMENTAL SETUP

3.1 *Principle of the test*

A schematic of the setup has been presented in figure 1. A sample in the cylindrical cell can be loaded in two different ways: using seepage pressures induced by flow generated by the flow pump (low stress levels) and/or using the hydraulic loading frame (high stress levels).
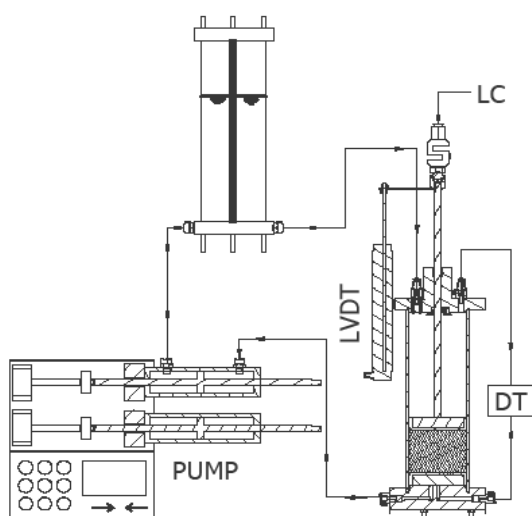

Figure 1. Schematic of the test setup

The procedure of loading using seepage pressure induced stresses (SIC test) is well described in literature (Imai 1979, Znidarcic et al. 1992). During the SIC test procedure, a pump generates a fixed flux through the sample, leading to stress changes and thus consolidation. The stress level increase can be controlled by choosing the flux rate.

From a certain point, loads can be applied using the loading frame. At the end of each load step, the pump is used to perform a permeability test. The flux rate is chosen to be small enough not to induce significant additional stresses on the sample.

The cell which is presented here is different from the typical setup in that the sample is tested in a completely separate cell, with an additional reservoir delivering the back pressure.

3.2 *Equipment*

The cell consists of a custom-made 90 mm diameter PMMA tube with a POM top and bottom cap. The sample is put between 2 perforated POM elements which, together with the intermediate filter papers, will act as the drained boundary conditions. They are very light and, when submerged, will induce a load onto the sample of less than 0.1 kPa. This (small) initial load has appeared necessary to avoid piping, especially at high flow rates.

The cell is 250 mm high in order to allow samples to be brought in at very low density to include the sedimentation process in the formation of the soil structure.

The bottom of the cell is connected to one side of an actuator mounted on the flow pump. The flow pump is a Harvard Apparatus model 33 which can be accurately programmed to give a specific flux rate. It also works in two directions, which, combined with automated switch valves on the actuators, allows to have a continuous test without the need for refilling and resetting the actuators. Each pump holds two actuators and therefore can be connected to two consolidation cells.

The water extracted at the bottom of the sample is moved to the top reservoir, which itself is connected to the top of the cell, thus closing the circulation loop.

Required measurements are made using a differential pressure transducer (DT) connected to top and bottom of the cell, a linear potentiometer (LVDT) to measure deformation of the sample and a load cell transducer (LC) to measure loads applied using the hydraulic loading frame.

All sensors are connected to a computer through an Agilent data logger controlled by a Labview program.

The full setup holds 6 cells, 4 of which are used for the SIC tests. The remaining two are used to prepare samples at a certain stress level which are later to be tested in a shear box. (Figure 2)
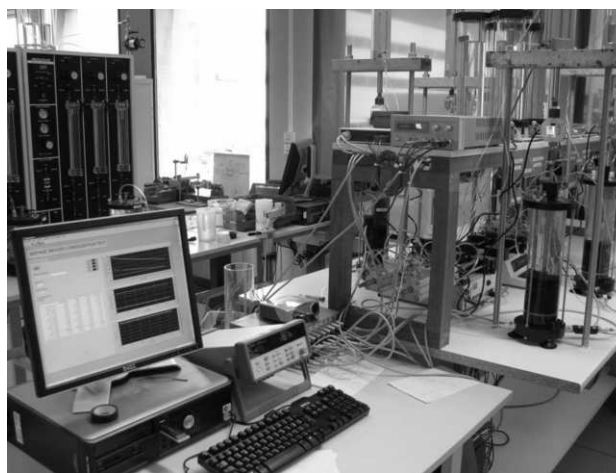

Figure 2. Photograph of the complete setup.

3.3 *Method of analysis*

For each loading step, either by seepage or by direct loading though the frame (combined with a small flux to determine permeability), we get a value for our main variables:

- h : sample height
- σ'_b : effective stress level at the bottom of the sample
- k : mean permeability over the sample

With these given values, parameters of the constitutive equations are determined using large strain consolidation theory (Gibson et al. 1967). The analysis is based on the methods used in the SICTA program (Abu-Heyleh 1992) but is executed using a solver engine in a spreadsheet program.

It is assumed that the constitutive equations are of the form proposed by Liu & Znidarcic (1991) and Somogyi (1979).

$$e = A \cdot (\sigma' + Z)^B \tag{1}$$

$$k = C \cdot e^D \tag{2}$$

4 TYPICAL RESULTS

Initial tests were performed on kaolin slurry to check testing procedures and perform adaptations to the equipment. The final results from a full test were confirmed with values from literature.

The first series of tests have been performed on mixtures of a gypsum-slurry with Greenfloc® (an anionic organic starch based polymer). The flocculant is quite weak compared to the typical commercial POE or PAM products but was initially chosen for its non-toxicity and biodegradability. Figure 3 shows the comparison of the compressibility and permeability curves for the original material and the mixtures using a weak flocculant.
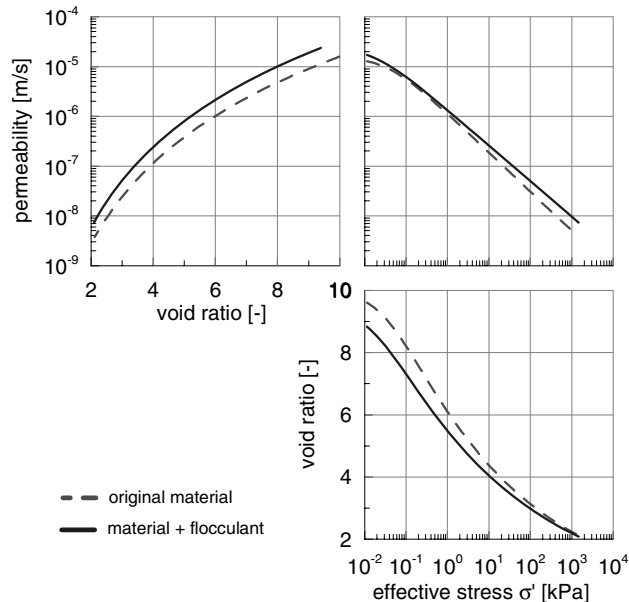

Figure 3. Typical result of the impact of flocculant on the large strain consolidation parameters

Both non-treated and treated material allowed a good fit between measured results and the constitutive equations given in equations (1) and (2). It still needs to be confirmed if higher concentrations or different type of flocculant would still result in functions of the same shape.

From the compressibility curve it is clear that the impact of the flocculant is limited to very low stress levels. The beneficial effect of the additive is however clear when looking at the permeability function. This shows that the structural change due to the presence of the additive can be maintained when going to large stress levels. The permeability shows an increased value over de full range of void ratios.

The difference in values is small but consistent with other test results. The tests will be repeated using stronger flocculants.

Based on the comparison of the two k(σ') functions one can define an improvement factor K* which could be a tool in the optimization protocol:

$$K^*(\sigma') = \left.\frac{k(\sigma')_{floc}}{k(\sigma')_{orig}}\right|_{\sigma'} \tag{3}$$

5 CONCLUSIONS

The paper has presented the initial work done in the framework of a MIP research project on the impact of additives on large strain behaviour of slurries.

An adapted version of the SIC test equipment has been developed and tested.

Preliminary results on mixtures of gypsum-slurries with and without flocculant have indicated that the flocculant induces a structural change in the material. This structural change is shown as an increased permeability over the full range of stresses.

The testing protocol and the determination of an improvement factor should allow optimising (economically) the type and concentration of an additive.

Further research will look into the development of shear strength and the impact of pre-existing soil structures on the consolidation behaviour.

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