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Consolidation and Hydraulic Conductivity Testing of Slurries

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Abstract

A prototype apparatus was designed for large strain consolidation and hydraulic conductivity testing of slurried materials. The apparatus consists of three parts; loading frame, consolidometer pot and constant head flow system. The unique design of the loading frame allows for large strains. The frame can accommodate consolidometer of various diameters and heights. Stainless steel rings with diameter of 152mm and height of 163mm have been used. Each consolidometer pot has ports for a series of manometers along its entire operating height that allows for monitoring of pore-water pressures during consolidation testing or heads during hydraulic conductivity measurement. The constant head system allows consolidation testing to be conducted with pre-selected constant back-pressure. The back-pressure can be selected to match head to be used in hydraulic conductivity measurement on completion of consolidation. This prevents disturbances to the hydraulic regime of the test specimen when going from consolidation test to hydraulic conductivity measurement.

Introduction

This paper describes consolidation and hydraulic conductivity testing of materials with high void ratio using a prototype apparatus. Testing of dredged materials and soft tailings presents a number of challenges. A variety of theoretical techniques for analysis are available, but laboratory techniques for adequately determining material properties and parameters for use in these theoretical analyses are lacking. It has been recognized that the major assumptions in classical small strain consolidation theory is highly restrictive for analysis of the large strains encountered in slurried materials. Finite strain models typically require that the stress and hydraulic conductivity be described as functions of void ratio. With slurried materials, there is also the gray area transitioning from a suspension to a soil phase. Consolidation essentially commences when a soil is subjected to a load. A slurry material typically starts out as a suspension of solids. The determination of the cessation of sedimentation, often referred to as zero-effective-stress condition presents some challenges.

A variety of laboratory techniques for consolidation and hydraulic conductivity testing of slurried materials have been developed. Some recent techniques include Cargill (1986) and Suthaker and Scott (1996). Some of these techniques involve two separate parts. The first part typically involves a self-weight consolidation test to determine the initial zero-effective-stress void ratio of the material. The self-weight consolidation test is similar to a sedimentation test. The second part is the consolidation test to be conducted on material commencing at zero-effective-stress void ratio for establishing relationships among effective stress, void ratio and hydraulic conductivity. These relationships are key information required in finite strain analytical modelling. Most laboratory techniques are strain controlled for faster completion of testing. Cargill (1986) found that coefficients of consolidation-void ratio relationships from constant rate of strain tests were consistently higher than those from stress controlled tests.

Major Issues and Challenges

The high void ratio (or low solids content) of slurried materials culminates in three main challenges for laboratory testing. These challenges are: 1. The equipment must be capable of accommodating large strains, 2. The equipment must have the ability to apply low loads at early stages of testing, and 3. The needs to minimize the negative impact of seepage-induced consolidation.

The issue of seepage-induced consolidation can be significant in dealing with slurried materials. Changes to void ratio and hydraulic conductivity are large in the early stages of consolidation. Also, the application of any gradient to measure hydraulic conductivity sets off seepage-induced consolidation. In one design (Suthaker and Scott, 1995; Scott et al., 1985), the loading cap was clamped to minimize seepage-induced consolidation during hydraulic conductivity testing.

New Testing Equipment

The equipment developed at MDH consists of three main components as follows:

- Loading frame.
- Consolidometer pot.
- Constant head system.

Loading Frame

The loading frame uses a mechanical system, consisting of a counterweight system, direct loading yoke and mechanical arm to provide mechanical advantages. A noteworthy feature of the loading frame design is that the applied loads are always confined within the perimeter of the apparatus, ensuring safety against overturning in the event of any mechanical failure (Figure 1).

The counterweight system is comprised of a weight adjustable counterweight block, a large pulley wheel, a yoke and a loading cap. The loading cap needs to be of significant thickness to accommodate the large strains encountered during testing. The combined weight of the loading cap and yoke is significant. This cap and yoke are balanced using an adjustable counterweight block. This counterweight can be finely adjusted giving the apparatus the capability of applying small loads.

Figure 1: Slurry consolidation and hydraulic conductivity testing equipment

Consolidometer Pot

Consolidometer pots are fabricated from stainless steel to avoid corrosion problems during long-term testing. The pots are designed for two-way drainage through the top and bottom. Drainage from the bottom can be closed off for one-way drainage only through the top. The lower porous stone is sealed into the base of the consolidometer pot to allow for hydraulic conductivity measurement. Flushing ports are located at the base for de-airing. Ports for manometers are distributed over the operating height of the pot for monitoring pore-water pressure during consolidation and head during hydraulic conductivity measurement. The LVDT for strain monitoring is locked in position by fastening to a stem that is fixed to the base of the pot. The LVDT can swivel in place without losing its reference. This enables for transfer of the consolidometer pot to a high pressure compression loader in the event there is a need for higher loadings. Also, this LVDT arrangement allows for the removal of the top collar in the event consolidation strain results in the cap moving below the surface of the consolidometer ring.

Constant Head System

The constant head system is comprised of a buret and a reservoir set-up. These are connected to the base of the consolidometer pot via a three-way valve such that connection can be made to either the buret or the reservoir. The constant head system is used for maintaining constant back-pressure during the entire test duration and for hydraulic conductivity measurements.

Slurry Sample Preparation

Tests can be conducted on undisturbed material or on thoroughly reworked materials. In many cases, test slurries with specific solids content are specified. In these instances, sufficient amount of slurry sample is mixed to produce a homogeneous sample. The homogeneous slurry sample is then poured into a consolidometer pot; at the same time a small sample is taken to determine initial water content and solids content. The initial mass of the sample, along with water content measurements and initial volume of the sample can be used to estimate the initial volume-mass properties of the test slurry. On completion of the laboratory test, the specimen is extruded from the consolidometer pot and the volume-mass properties of the specimen are determined. Figure 2 shows a photo of an extruded mature fine tailings MFT specimen taken at the end of the consolidation test.

Figure 2: An extruded MFT specimen at the end of the consolidation test

Typical Test Results

Some preliminary test results are presented in this section. Deflection-time data for a mine tailings sample subjected to an applied stress of 0.5 kPa are presented in Figure 3. The mine tailings contained significant fines but had little clay content. Time for completion of primary consolidation of the mine tailings under 0.5 kPa was of the order of 2 weeks. Deflection-time data for a MFT sample are presented in Figure 4. The MFT had significantly higher clay content. Time for completion of primary consolidation in the case of the MFT was of the order of 4 weeks. Results show that consolidation time can be long and this is due to significantly large sample sizes as well as hydraulic conductivity of the materials.

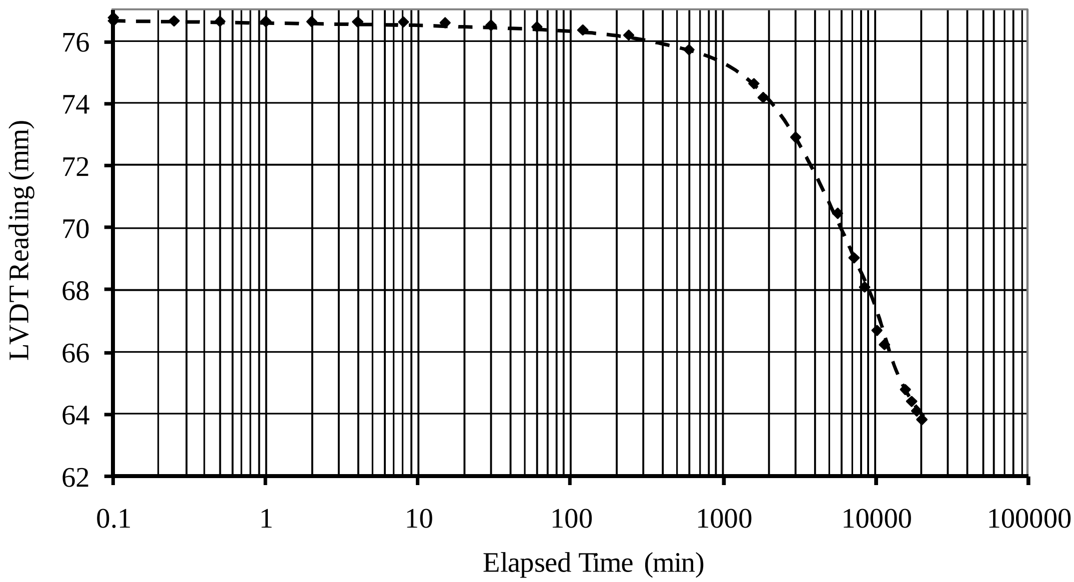

Figure 3: Deflection-time data for a mine tailings sample at 0.5 kPa stress

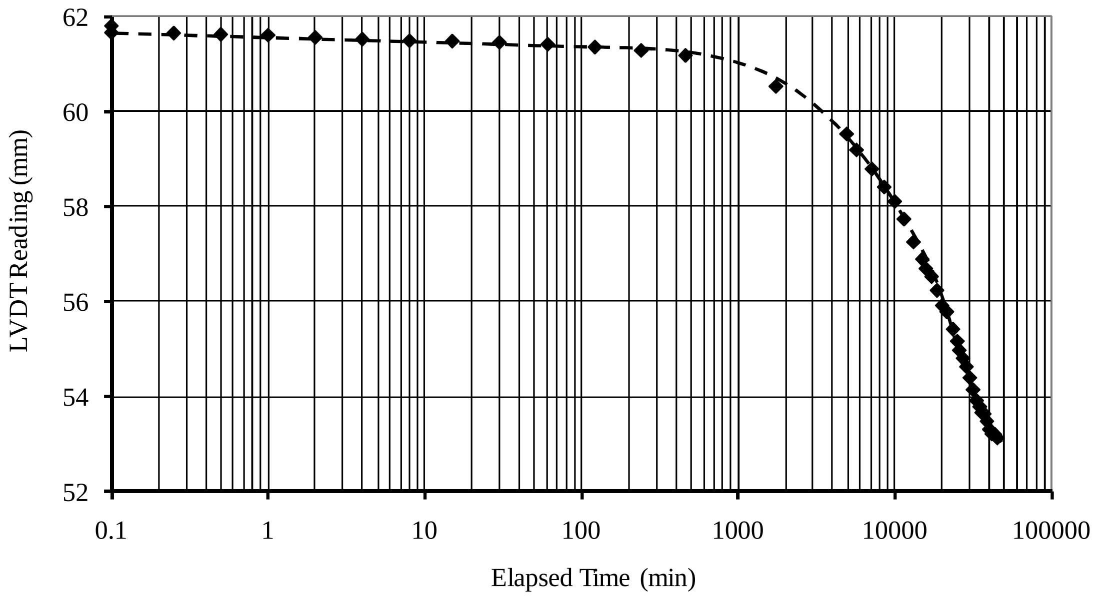

Figure 4: Deflection-time data for a MFT sample at 2.2 kPa stress

A set of e-log p curve data for a mine tailings is presented in Figure 5. No attempt was made to determine the zero-effective-stress void ratio in this test. The tailings were prepared as a slurry at an initial solids content of about 29%, with a theoretical void ratio of 6.4. The sample was a suspension at the start, and first load corresponding to 0.5 kPa was applied soon after the sample was set up in the equipment.

A set of e-log p curve data for a MFT sample is presented in Figure 6. The material was previously dewatered in the field and the sample was set-up in the testing equipment in a relatively undisturbed state. The sample had an initial void ratio of about 4.9. The first load applied was of the order of 0.2 – 0.3 kPa.

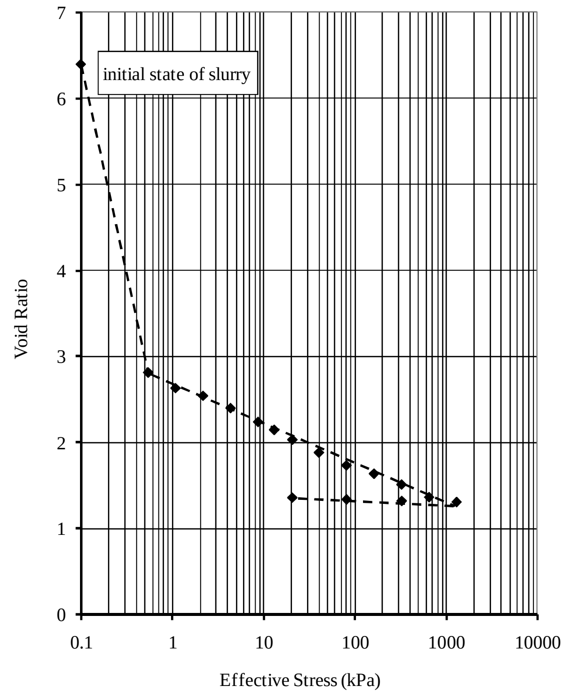

Figure 5: Void-ratio versus effective stress data for a mine tailings sample

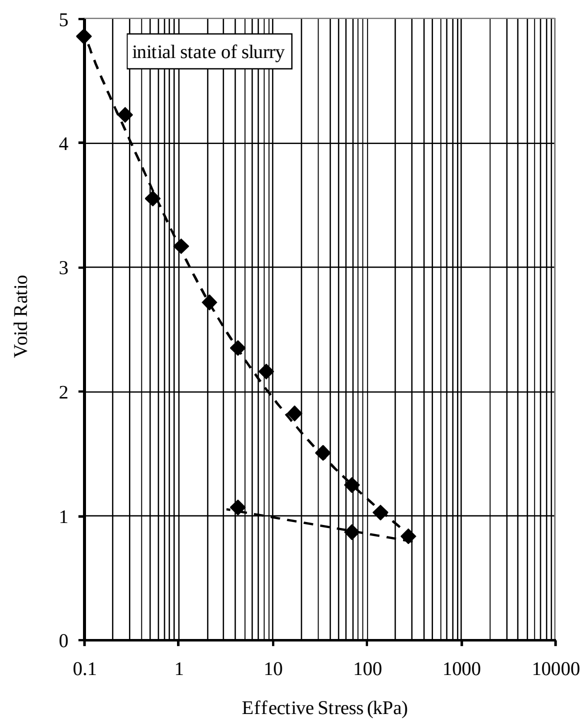

Figure 6: Void-ratio versus effective stress data for a MFT sample

Hydraulic conductivity measurements conducted at completion of primary consolidation corresponding to a selection of consolidation pressures for a mine tailings sample are presented in Figure 7. The e-log k curve in Figure 7 shows a gradual reduction in hydraulic conductivity of about one order of magnitude, from 1E-07 m/s to 1E-08 m/s, as void ratio decreases from about 2.2 to about 1.6.

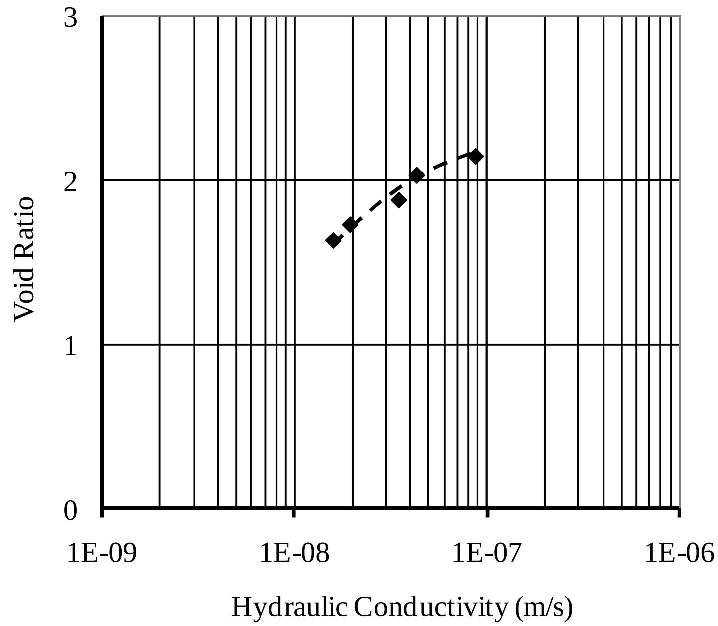

Figure 7: Void-ratio versus hydraulic conductivity relationship for a mine tailings sample

Conclusions

A slurry consolidation prototype testing apparatus has been developed for large strain consolidation testing. The equipment has been used for large strain consolidation tests and hydraulic conductivity measurements on various materials such as mine tailings slurry and dewatered MFT sample. Various improvements are still being developed on the equipment for future testing. The apparatus is intended to lead to improved precision in testing of slurried materials.

References

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