Consolidation characteristics of soft sediments; Newark bay case study

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ABSTRACT

The consolidation characteristics of soft sediment dredges from Newark bay area, New Jersey, is investigated through seepage induced consolidation test device. In this paper the seepage induced consolidation test device was constructed and used to evaluate compressibility and permeability behavior of fine, low density sediments. Conventional consolidation tests usually involve restrictive assumptions on the amount of strain, hydraulic conductivity and coefficient of consolidation which makes them impractical dealing with soft sediments at low stress levels. The soft nature of dredged material and mine tailings hinders using conventional consolidometers for testing purposes. It is difficult to test the compressibility and permeability of these types of sediments at low effective stresses. Therefore a consolidation cell, based on seepage force was constructed based on seepage induced consolidation tester (SICT) at University of Colorado at Boulder and the consolidation characteristics of soft sediments dredged from seabed is investigated.

Results of this research program showed that this method of testing is applicable to the soft sediment consolidation testing and provides reliable and repeatable results.

Keywords: Soft sediments, Seepage induced consolidation

1 INTRODUCTION

Every year millions of cubic yards of sediments have to be dredges from sea beds or waterways in order to create required depth for boats and ships to be able to get in and out of ports. Many of the land filling works in ports and waterways are in general carried out by hydraulic dredging of seabed sediments and the pumping the dilute soil-water mixture which is called slurries into dyked ponds located near the shore. Accurate design of the catchment ponds and dikes for this vast amount of dredges requires knowledge of the consolidation characteristics of these materials.

The fine nature of the sediments with high water content restricts the usage of traditional consolidometer. In fact soil particles as a result of physic-chemical interactions between the particles tend to settle down in flocs and therefore the compression of particles starts with very low effective stresses. Since the specific gravity and buoyant weight of flocs are very small, self-weight consolidation starts from very low effective stresses which causes the conventional oedometer test to be ineffective.

2 CHARACTERISTICS OF NEWARK BAY DREDGED MATERIAL

Sediment from the Newark bay spans a wide range of material type form clean Pleistocene clay to fluid mud contaminated by industrial discharge. Sediments deposited in previously-dredged navigation channels and bays is often fine grained, organically enriched with some amount of contamination. But the quality of water has improved steadily over the past several years so the amount of contamination is not the concern in this study. Since using the dredged material for beneficial purposes like fill or capping landfills is the purpose of any office of maritime resources program, the consolidation properties of abovementioned material has been investigated. Since the consolidation of these types of material is extremely slow, the standard consolidation testing procedure is inadequate. The approximate location of the dredging station is shown in figure 1. The average of index properties of the soil in this study is presented in table 1.
There are a number of experimental tests suggested by researchers in order to investigate the consolidation characteristics of soft sediments with high water contents (Znidarcic & Liu, 1989). The idea of consolidation under seepage was proposed by Imai (Imai, 1979) but the setup was developed by Znidarcic in 1989. The consolidation based on seepage force has a number of advantages like compressibility and hydraulic conductivity relationships of the material can be obtained in one test but in multiple steps.

The Seepage Induced Consolidation Test (SICT) has been developed (Abu-Hejleh & Znidarcic, 1996) and used for over two decades to determine the consolidation characteristics of soft sediments such as dredged sediments, mine tailings. The efficient procedure of the test can result in the permeability and compressibility relationship of the soft sediment.

The SICT test consists of three stages which the first stage is sedimentation column in order to get zero stress void ratio, the second stage is consolidation under low effective stresses created by seepage force and the last stage is consolidation under load which result in void ratios in these stages accordingly. The first stage is the sedimentation column which is aside from the actual seepage test apparatus and may take weeks to be completed. In first stage the slurry from the dredging station will be poured into graduated cylinder and will be left to settle down under its own weight. The average void ratio of the settled material will be considered as zero stress void ration $e_{00}$.

The second and third stage will be performed in the SICT device which is shown in figure 2. The device has been built based on the help of Prof. Znidarcic and is a duplicate of the same device in university of Colorado with simplified modifications for easier troubleshooting. The device is consisted of syringe pump to induce suction from underneath of the sample, sample chamber, data acquisition unit to monitor and record the axial deformation, seepage rate, stresses and finally the differential pressure transducer for monitoring and recording the difference in pressure between top and bottom of sample.

In the second stage of the test the small amount of stress due to seepage force will be induced on the sample by sucking the water out of the sample chamber from underneath of the sample and the axial deformation and hydraulic conductivity will be recorded.

The final stage of the test is loading the sample to desired stress level and inducing the lowest possible seepage force in order to record both hydraulic conductivity and sample axial deformation. Based on the recorded data the void ratio in each stage will be calculated and at the end of the test the sample will be taken out of the chamber and will be dried in oven and the total volume of solids will be calculated.

The results of the test will be analyzed by Excel spreadsheet based on SICTA program principles (Abu-Hejleh & Znidarcic, 1994). The compressibility and hydraulic conductivity relations with void ratio is based on equation proposed by Znidarcic. The proposed equation for compressibility is:

$$e = A(\sigma' + Z)^B$$

And the hydraulic conductivity is based on:

$$K = C \times e^D$$

In these equations $e$ is void ratio, $\sigma'$ is effective stress and $K$ is the hydraulic conductivity. $A$, $B$, $C$, $D$, and $Z$ are the model parameters which are used to...
predict the consolidation behavior for all stress levels.

The algorithm of solution for compressibility equation is based on three void ratio values in three stress levels i.e. zero, Seepage stress and final stress respectively. Then the solver function of the Excel program is used in order to find the best fit answer for three power equations with three unknowns (A, Z and B). The similar procedure can be used to find the solution for two equations with two unknowns for hydraulic conductivity and void ratio equation. Since there are two different stages for doing the test when it is in SICT apparatus then we can have two hydraulic conductivity values corresponding to two void ratios in seepage stage and load stage.

4 BENCHMARK TESTS OF KAOLINITE CLAY

Kaolinite clay were used to compare the data with published data by Estepho et al. (2013) and confirm that the test setup provides reliable and repeatable data sets. Therefore three samples were prepared based on 42 percent solid content which is equivalent to 136 percent moisture content to create the suitable slurry for testing. The average results based on three tests and published data on CU boulder samples and UBC samples are compared in figure 3. The constitutive relationship is presented in table 2.

![Fig. 3. Benchmark test on Kaolinite clay](image)

<table>
<thead>
<tr>
<th>Table 2. Constitutive relationships on Benchmark test</th>
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<tbody>
<tr>
<td><strong>Void Ratio - Stress</strong></td>
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<tr>
<td><strong>Rutgers</strong></td>
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<tr>
<td><strong>CU-Boulder</strong></td>
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<tr>
<td><strong>UBC</strong></td>
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The results of benchmark test at Rutgers shows that although the test setup is modified to use deadweight for simpler troubleshooting purposes but the result is quite satisfactory and reliable.

5 TEST RESULTS

As stated in the previous section, ten seepage induced consolidation test has been performed in order to investigate the consolidation properties of the Newark bay sediments. The testing program starts with self-weight consolidation which allows the slurry sample to settle down under its own weight which always takes two to three weeks to be completed. Then the sample is prepared for the seepage test by measuring the moisture content and specific gravity and the first stage of seepage test will be performed. In this stage the sample is subjected to seepage force caused by suction pump and stress because of porous stone, top cap and plunger on top which is usually about less than 0.5 kPa and will take almost a day to be completed. Then the last stage of the test will begin which might have multiple steps to densify the sample for desired stress level. The last stage of test usually starts with 1 kPa stress for a day under minimum hydraulic conductivity induced on the sample and then will continue with 10, 25 and 100 kPa stress levels, but in order to process the data for model parameters (A, B, C…) we just need one of these points and the other loading steps are redundant. Usually the testing program will include two to three weeks for the self-weight consolidation stage and one week for loading the sample in multiple steps to reach the desire stress level based on application. The overall result for four tests, out of ten, is presented in Figure 4 and 5 for compressibility and hydraulic conductivity respectively.

![Fig. 4. Void Ratio vs Stress](image)
Table 3 summarizes the compressibility and hydraulic conductivity equations based on the models presented earlier. This model specially is well suited for zero effective stress and can overcome other models shortcomings.

6 DISCUSSION

The results of the seepage induced consolidation test suggest that the soft sediments of Newark bay undergo consolidation process when subjected to small stresses. The low hydraulic conductivity and high compressibility of these materials are obtained based on seepage induced consolidation test. The SICT tests will be performed in three major steps, including self-weight, small stresses below 0.5 kPa and high stress level based on the application. Each test needs to be done in redundant steps in order to densify the soft sediment for higher loads but in fact three stresses and corresponding void ratios are enough to get the void ratio compressibility equation. This research showed promising results that the testing setup is well suited for investigating consolidation behavior of soft dredged sediments. Figure 4 shows the compressibility of the material in different void ratios and as can be seen by increasing the effective stress the void ratio will decrease and the model can well display the behavior of the graph in zero effective stress. The reduction in hydraulic conductivity as consolidation takes place is shown in figure 5. It should be noted that each complete consolidation test, based on the desired stress level, may need two to three weeks to be completed.

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REFERENCES


