Plaisted, M.D., and Zornberg, J.G. (2010). “Testing of an Expansive Clay in a Centrifuge Permeameter.” Proceedings of the *7th International Conference on Physical Modelling in Geotechnics* (ICPMG 2010), Zurich, Switzerland, June, Vol. 2, 28 June-01 July, pp. 1477-1481.

Physical Modelling in Geotechnics – Springman, Laue & Seward (eds)
© 2010 Taylor & Francis Group, London, ISBN 978-0-415-59288-8

Testing of an expansive clay in a centrifuge permeameter

M.D. Plaisted & J.G. Zornberg
The University of Texas at Austin, USA

ABSTRACT: A research project was conducted on the use of centrifuge technology to characterize the expansive properties of a highly plastic clay. Direct quantification of the swelling of clays has been typically avoided because of the significant testing times involved. The research focused on the development of a testing procedure using a non-instrumented and inexpensive centrifuge that can provide direct, expeditious measurement of swelling. The testing procedure developed was found to produce highly repeatable results with testing duration generally of a few days. The results of the experimental program indicate that centrifuge testing can be used to quickly and directly characterize the expansive properties of expansive clays rather than relying on questionable correlations to determine swelling potential.

1 INTRODUCTION

A research project was conducted with the objective of characterizing the swelling of highly plastic clays using a centrifuge permeameter. These tests aim at improving the current practice of using conventional free swell tests by decreasing testing time and also by providing a clear termination stage (steady state) for swell tests. This study, conducted using a comparatively inexpensive, non-instrumented centrifuge device complements ongoing research at the University of Texas at Austin involving the use of a sophisticated centrifuge permeameter that incorporates the use of in-flight data acquisition and flow control under comparatively high g-levels (Zornberg & McCartney 2010).

Conventional free swell tests (ASTM D 4546-08) are performed in consolidation frames. Samples are compacted in consolidations cells and an overburden pressure is applied through the consolidation frame. Water is then poured around the sample and deflections are measured as the sample swells. There is no clear termination point and tests often run for a month until the sample height appears to come to equilibrium. The long duration of conventional tests has led to the use of questionable correlations based on soil index properties rather than on the direct measurement of the soil swelling potential. It is hoped that the centrifuge testing procedure will provide a quick and inexpensive method for direct measurement of the swelling properties of clays, which represent a significant improvement over the conventional use of often inaccurate correlations.

Previous research of expansive clays using centrifuge technology (Frydman & Weisberg 1991; Gadre & Chandrasekaran 1994) involved instrumented centrifuges that are typically aimed at research projects rather than at soil characterization in conventional soil laboratories. This research project explored the use of a non-instrumented centrifuge with the goal of developing an inexpensive, implementable test for quickly determining the expansive properties of highly plastic clays.

2 TESTING EQUIPMENT

The centrifuge used in this research study is a Damon/IEC centrifuge. This model is the “IEC EXD,” which is a floor mounted centrifuge that has been used for a variety of industrial purposes. It contains four hangers that hold freely swinging aluminum centrifuge cups. The setup of the centrifuge is fairly customizable, as the contents of the centrifuge cups can be altered to fit requirements of different tests. Plastic permeameter cups that fit inside the centrifuge cups were designed and manufactured specifically for this research project. The main components of the centrifuge are discussed individually in the following sub-sections. The centrifuge can be observed in Figure 1. The centrifuge speed is controlled by a power setting knob on the side of the base. The power setting ranges from 0–100 and correlate with a power level for the electric motor.

The testing setup used in this study involved ponding water on top of a compacted soil sample and spinning the sample at comparatively high comparatively high g levels (ranging from 25 to 400 g). The increased g level leads to an increased hydraulic gradient that forces the water through the samples at an increased rate that promotes expeditious swelling of the clay. A simplified diagram of the test setup is shown as Figure 2.

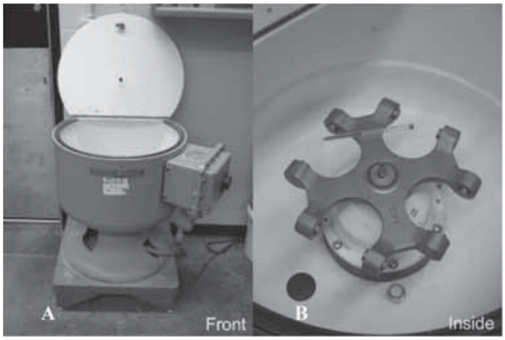

Figure 1. IED EXD Centrifuge: a) Front view b) Inside view of hangers.

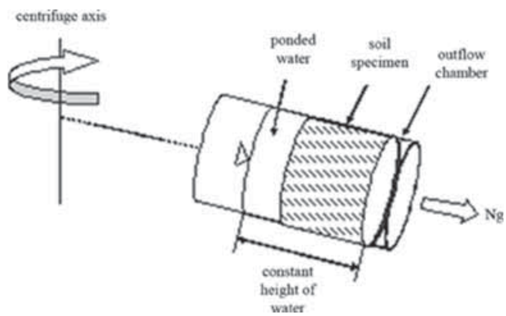

Figure 2. Centrifuge test setup.

2.1 *Centrifuge cup*

The centrifuge cups (Fig. 3a) hang from the spinning centrifuge arms and were provided with the centrifuge and have not been significantly modified as part of this study. The holders have an inner diameter of 6.35 cm and a usable inside depth of 11.43 cm. The base of the specimen holder includes a small vent hole to allow air and water outflow. When in flight the distance from the base of a sample to the center of rotation in the small centrifuge is 16.5 cm.

2.2 *Permeameter cup*

The permeameter cups (Figure 3b) fit inside the centrifuge cups and have an outside diameter of 6.33 cm and a depth of 11.43 cm. The cups have an inside diameter of 5.72 cm at the top, which is reduced to 4.71 cm approximately 2.5 cm from the base of the cups. This reduction was adopted to form a ledge that allow a porous plate to support soil samples. The base of the cup is removable and is used as a liquid collection system. Outflow can be measured accurately by measuring the increase in weight of the collection cup. A small air vent

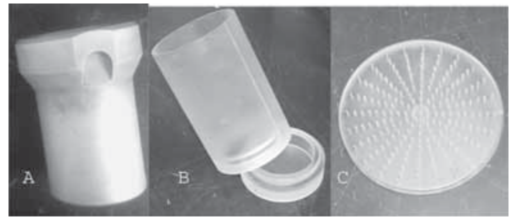

Figure 3. Centrifuge components: a) Centrifuge cup b) Permeameter cup c) Porous disc.

(visible in Fig. 3b) connects the collection cup to the area above the sample to allow equalization of air pressure between the chambers located above the ponded water and at the bottom of the sample.

2.3 *Porous supporting plate*

The porous supporting plate (Fig. 3c) sits on top of the ledge in the permeameter cup and creates a firm yet pervious surface to place specimens. The plate contains a number of 0.8 mm-diameter holes that allow water to flow freely from the base of the specimen. To avoid migration of soil particles, a filter paper is placed between the porous plate and the soil specimen.

2.4 *Permeameter cap*

A rubber permeameter cap fits inside the top of the permeameter cup in order to prevent excessive evaporation during testing. The rubber cap provides an airtight seal once the centrifuge is in flight.

3 SOIL CHARACTERIZATION

The expansive soil used in this research study is a highly plastic clay shale from the Eagle Ford formation in Round Rock, Texas. The characterization of the clay has been reported previously (Kuhn 2005) and a summary of soil properties is included as Table 1.

The Eagle Ford clay shale is considered to be one of the most expansive clays found in Texas. As indicated in Table 1, this clay has a very low saturated hydraulic conductivity (8.9×10^{-8} cm/s), a high liquid and plastic limit (88 and 39 respectively), and a comparatively high optimum water content at standard proctor compaction (24%). The Eagle Ford clay is composed by approximately 75% clay minerals of which 50% have been reported to be smectites (Hsu & Nelson 2002). Standard one-dimensional swell tests were performed on the soil in consolidation frames with overburden pressures

Table 1. Properties of Eagle Ford Clay.

Property	Value	ASTM standard
Specific gravity	2.74	D 845-02
Liquid limit	88	D 4318
Plastic limit	39	D 4318
Shrinkage limit	18	D 4943
Particle size:		
Passing 0.075 mm	97%	D 422-63
Passing 0.002 mm	76%	D 422-63
Standard proctor:		
Optimum water content	24%	D 1557
Maximum dry unit weight	15.2 kN/m^3	D 1557
Modified proctor:		
Optimum water content	14%	D 695
Maximum dry unit weight	17.8 kN/m^3	D 698
Hydraulic conductivity	8.9×10^{-8} cm/s	D 5084

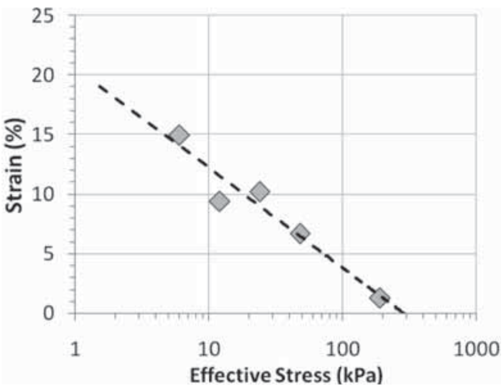

Figure 4. Standard free swell test results.

ranging from 6 kPa (standard overburden pressure for free swell testing) up to 200 kPa. The results of the completed free swell tests can be observed in Figure 4. A best fit logarithmic relation is also shown in the figure.

The free swell tests resulted in high swell values, with approximately 15% swell obtained at a confinement of 6 kPa. Based on the relationship defined by five tests performed, the swell pressure was determined to be approximately 300 kPa.

4 TESTING PROCEDURE

Soil was compacted in one centimeter lifts in the permeameter cups at optimum water content and standard proctor density using kneading compaction. A view of the kneading compactor used

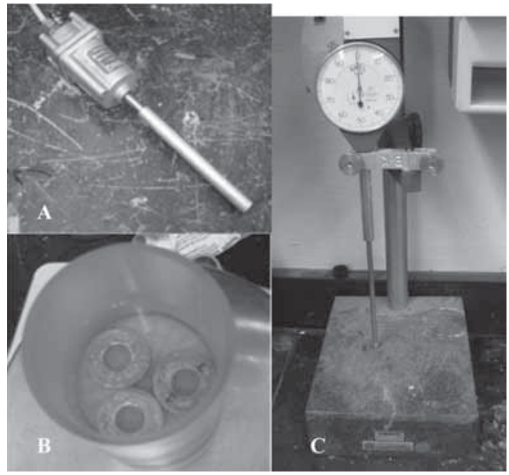

Figure 5. Measurement and preparation devices: a) Kneading compactor b) Overburden washers c) Mounted caliper.

in this investigation is shown in Figure 5a. The kneading compactor allows a constant pressure to be applied to the soil surface during compaction increasing repeatability. Sample heights of one, two, and three centimeters were tested as part of the feasibility study. A height of two centimeters was eventually selected as the standard height for testing based on the good repeatability of test results and the comparatively small test duration. The selected standard testing procedure also involved use of two centimeters of water ponded on top of the compacted samples and of approximately 12 grams of washers placed on top of the porous disc to apply an overburden in flight. The setup of washers on top of the samples is shown as Figure 5b.

Samples were then spun in the centrifuge and removed approximately every 12 hours to measure sample height and outflow. A vertically mounted caliper (Fig. 5c) was utilized to expeditiously measure the variation in specimen height. Two samples were tested simultaneously in each test. The process of turning off the centrifuge, removing and measuring samples, and spinning up the centrifuge again typically took approximately 5 minutes for both samples.

Testing length was dependent on several factors including sample height, g-level, and water head and ranged between one and five days. During the preliminary testing program, it was found that the sample height was the major factor effecting testing duration. This was due to water front requiring additional time to reach the base of the sample when the sample height was increased. Generally, one centimeter samples reached their ultimate

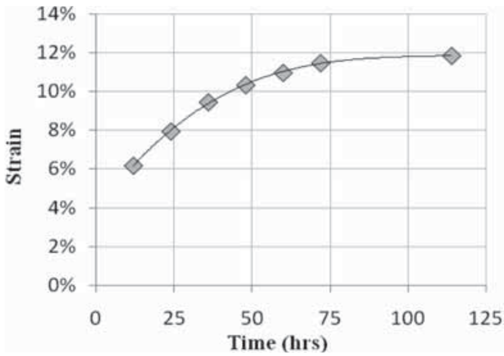

Figure 6. Swell over time of centrifuge sample.

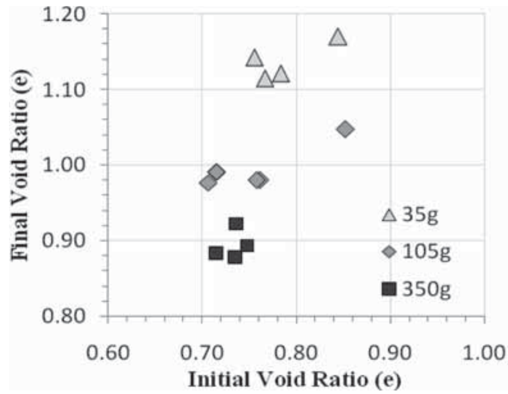

Figure 7. Centrifuge test results.

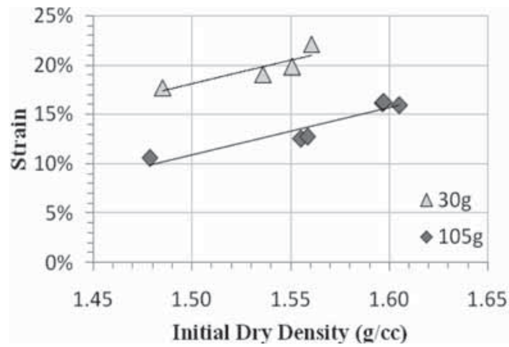

Figure 8. Relationship between initial dry density and strain after swelling.

swelling value after two days, two centimeter samples completed swell after four days. Three centimeter samples did not come to equilibrium after a week and further testing was not completed. The selected g-level and the water head were found to have a comparatively smaller effect on the overall test duration.

A typical result illustrating the swelling over time of a centrifuge test is shown in Figure 6. The results shown in the figure correspond to a two cm-tall sample flown at a g-level of 100 g. These results are typical of those obtained in the rest of the tested specimens. Once the time for swelling to complete was determined from a test with incremental readings, additional tests were completed with readings taken only at the initial compaction condition and the final reading.

Additional information on the testing procedure along with a complete analysis of the test results can be found in Plaisted (2009).

5 RESULTS

A series of tests were completed on the Eagle Ford clay using g-levels of 35, 105, and 350. The initial void ratios of the clay (at compaction) are shown against the final average void ratios (after completion of tests) in Figure 7. For tests flown at g-levels of 35 the final void ratios were approximately 1.14. Samples flown at g-levels of 105 resulted in final void ratios of approximately 1.00 and samples flown at a g-level of 350 resulted in a final void ratio of 0.90. While the full evaluation of these test results is beyond the scope of this paper, these test results allowed determination of the full relationship between swelling and confining pressure for Eagle Ford Clay.

The initial compaction conditions were found to have a significant effect on the final average void ratio of the sample. For a given increase in initial void ratio, the final void ratio was found to increase by approximately half of the increase in initial void ratio. The initial void ratio varied between 0.70 and 0.85 (target of 0.76). This resulted in a range in final average void ratios of approximately 0.05.

The data for the swell tests is also provided as initial dry density against axial strain in Figure 8. The measured swell percent increases as the density increases. The slope of the increase was similar for both g-levels, increasing 3% swell for a 0.05 g/cc increase in initial dry density. The data for tests run at a g-level of 350 is not included in the figure as the initial dry density did not vary enough to define a clean trend.

The comparatively small scatter observed in the data collected to define the relationship between dry density and strain provides good evidence of the good repeatability of the centrifuge testing procedure used in this investigation. The maximum deviation between the strain predicted by the relation and the measured test result was around 1% based on this testing set.

6 CONCLUSIONS

The use of a non-instrumented, inexpensive centrifuge procedure was developed to characterize the swelling potential of a highly plastic clay. The following conclusions can be drawn from this investigation:

- The centrifuge test was shown to produce highly repeatable results of the swelling potential of the Eagle Ford clay.
- The testing procedure required test durations that were primarily a function of the selected sample height.
- Two centimeter-high samples showed no significant swell after approximately four days.
- The swelling potential of the Eagle Ford clay decreased with increasing g-level as a result of the increased stress level in the samples.
- Tests with comparatively higher initial void ratios were observed to reach their ultimate swelling at higher final void ratios.
- The measured axial strain of samples due to swelling increased as the initial density increased.

Further research is under way in order to more accurately define the time savings benefits of using centrifuge testing over free swell testing. Specifically, the results of centrifuge tests are being analyzed by comparing them with swell values measured from standard tests conducted during extended periods of time.

REFERENCES

Frydman, S. & Weisberg, E. 1991. Study of centrifuge modeling of swelling clay. *Proceedings of the International Conference Centrifuge:* 113.

Gadre, A. & Chandrasekaran, V. 1994. Swelling of black cotton soil using centrifuge modeling. *Journal of Geotechnical Engineering* 5: 914–919.

Hsu, S. & Nelson, P. 2002. Characterization of Eagle Ford Shale. *Journal of Engineering Geology* 67: 169–183.

Kuhn, J. 2005. *Effect of cracking on the hydraulic properties of unsaturated highly plastic clays.* Master's thesis, University of Texas.

Plaisted, M. 2009. Centrifuge Testing of Expansive Clay. Master's Thesis, University of Texas at Austin.

Zornberg, J.G. & McCartney, J.S. 2010. Centrifuge Permeameter for Unsaturated Soils I: Theoretical Basis and Experimental Developments. *Journal of Geotechnical and Geoenvironmental Engineering,* ASCE, in press.