Reference: Ruffing, D. G., and Evans, J. C., (2010) " In Situ Evaluation of a Shallow Soil Bentonite Slurry Trench Cutoff Wall "
Proceedings of the 6th International Congress on Environmental Geotechnics, New Delhi, India,
Tata McGraw-Hill ISBN 13:9780070707108, pp. 758-763.

In Situ Evaluation of a Shallow Soil Bentonite Slurry Trench Cutoff Wall

Daniel Ruffing
Bucknell University, Project Engineer, Geo-Solutions Inc, New Kensington, PA 15068 USA
druffing@geo-solutions.com
Jeffrey C. Evans, Ph.D., P.E.
Bucknell University, Department of Civil and Environmental Engineering, Lewisburg, PA 17837 USA
evans@bucknell.edu

ABSTRACT Soil bentonite (SB) slurry trench cutoff walls have been widely used in the USA to control ground water flow and the migration of contaminants in the ground water. While substantial laboratory testing has been conducted, field studies are limited. Researchers at Bucknell University were afforded the opportunity to conduct a suite of *in situ* tests on a SB cutoff wall constructed during the summer of 2008. Cutoff wall properties were measured *in situ* employing cone penetration tests (CPT), Marchetti dilatometer tests (DMT), vane shear tests (VST), and ground water level monitoring on both sides of the wall. Tests were conducted during construction and at times of 3 months, 6 months and 9 months after construction to evaluate the change in wall properties with time. In addition, bulk samples and a Shelby tube SB backfill sample were obtained during construction for laboratory testing which included water content, grain size distribution, consolidation and rigid wall hydraulic conductivity. The field and laboratory data were analyzed to develop a consistent understanding of the *in situ* properties of the cutoff wall backfill. The VST and CPT showed an increase in backfill shear strength over the time-frame of the study. A slight increase of shear strength with depth was also found. However, a comparison of shear strength measured compared with that predicted using typical ratios of strength to consolidation stress indicated that the *in situ* stress is less than that expected. Laboratory testing revealed a decreasing hydraulic conductivity with increasing consolidation stress demonstrating the importance of a reliable estimation of the stress state in the wall.

INTRODUCTION

Soil bentonite (SB) slurry trench cutoff walls are commonly used as vertical barriers for the control of groundwater and subsurface contaminant flow. Despite some research efforts devoted to these walls in the laboratory, limited field studies have been conducted to determine how these walls behave *in situ*. (National Research Council 2007). Previous research indicates that the stress is less than that which a geostatic (triangular) pressure distribution would predict (Evans et al. 1995, Filz 1996, Ruffing et al. 2010).

Late in the summer of 2008, researchers at Bucknell University were afforded the opportunity to conduct a suite of laboratory and *in situ* tests on a shallow SB cutoff wall constructed in Eastern Pennsylvania. This wall was constructed under the technical guidance of Geo-Solutions Inc. to control ground water flow beneath a municipal wastewater facility in Birdsboro, PA. A flood control dike and the SB wall were built to limit inflow of ground water such that below grade wastewater tanks do not become buoyant during flooding events of a nearby river. The barrier wall is approximately 1400 m^2 and 4.5 m deep at its deepest point. Design studies showed that the desired hydraulic conductivity ($1 \cdot 10^{-6}$ cm/s) could be achieved by simply blending the excavated soils with bentonite-water slurry due to the high percentage of natural fines along the trench alignment. However, during construction, approximately one percent dry bentonite was added. A clay core dike was installed on top of the wall to prevent surface water flooding of the site.

Quality control testing was conducted by Geo-Solutions Inc. to ensure that the finished wall had met the design specifications. A summary of the properties collected during this QC testing is shown on Table 1.

Table 1. QC Properties of Birdsboro Wall

	Site Specific Requirement	QC Results Range
Fresh Slurry		
Marsh Viscosity (sec)	> 36	37 - 38
Mud Density (kN/m^3)	> 10.1	10.4 – 10.6
Filtrate Loss (ml)	< 20	16 - 19
pH	6.5 - 10	9 - 9.5
Trench Slurry		
Marsh Viscosity (sec)	> 40	41 - 45
Mud Density (kN/m^3)	10.1 – 13.4	10.6 – 12.1
Filtrate Loss	< 30	17 - 24
Sand Content	< 15	1 - 11
Backfill Properties		
Backfill Unit Weight (kN/m^3)	> 15.8	17.3 – 21.0
Percent Fines (%)	> 30	41 - 55
Slump (mm)	76 - 127	51 - 146
Moisture Content (%)	varies	24 - 51

Field testing was conducted on the wall immediately after construction and after the wall had aged 3, 6, and 9 months. This field testing included cone penetration tests (CPT), Marchetti dilatometer tests (DMT), and vane shear tests (VST). Groundwater monitoring wells were installed inside and outside of the wall for long-term monitoring of the ground water on both sides of the wall. Along with field testing, both an "undisturbed" backfill sample using a thin-walled sampler and bulk backfill samples were taken on the day of construction. Laboratory tests performed on the field mixed backfill samples included Atterberg limits, moisture content, and grain size distribution by sieve and hydrometer. Along with these physical property tests, one-dimensional consolidation tests were conducted on three remoulded samples of the backfill. The hydraulic conductivity was measured at each consolidation effective stress to determine the relationship between hydraulic conductivity and consolidating stress for this backfill.

METHODS AND MATERIALS

Laboratory testing was conducted in Bucknell University's Geotechnical Engineering laboratory. The Atterberg limit tests and sieve test were conducted according to ASTM D4318-05 and ASTM D422-63 respectively. Classification of the backfill was conducted according to ASTM D2487-00. Consolidation and hydraulic conductivity testing followed closely the procedures in ASTM D2435-04 and Yeo et al. (2005) respectively. The CPT testing followed the procedure presented in ASTM D5778-07 and the data was analyzed using principles from Powell and Lunne (2005), and more specifically, the effective cone method with two different correction factors. DMT testing and data analysis followed the procedures in Schmertmann (1988) combined with recommendations from ASTM D 6635-01. Finally VST testing followed the procedures in ASTM D2573-01. More detailed procedures can be found in Ruffing (2009).

RESULTS

The liquid and plastic limits of the backfill were found to be 28 % and 17%, respectively, resulting in a plasticity index of 11%. The moisture content of the freshly placed backfill ranged from 24% - 31% with an average of 28% indicating that the backfill was placed in a viscous liquid condition (it was placed at a slump of 2 to 5.75 inches as shown on Table 1). The grain size distribution from the sieve and hydrometer tests is shown on Fig. 1. The grain size distribution and Atterberg Limits were used with the USCS classification system to classify the SB backfill as a SC, a silty clayey sand with gravel. Figure 2 shows the results with error bars of one-dimensional consolidation tests conducted on triplicate samples. These remoulded samples were taken from a Shelby tube sample of the backfill collected immediately after construction. The compression index of the backfill was 0.16 and the modified compression index was 0.10.

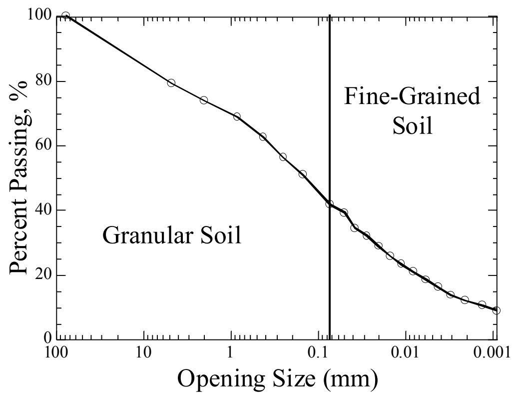


Fig. 1 Grain Size Distribution for Birdsboro Backfill

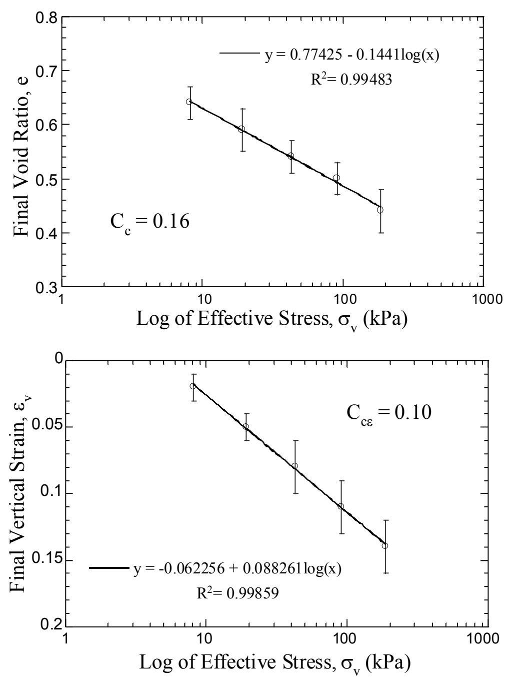


Fig. 2 Results of Consolidation Tests

Figure 3 presents the results of hydraulic conductivity tests (rigid wall) that were conducted at each consolidation load in order to evaluate the effect of consolidating pressure (over the range expected in an SB wall) on the hydraulic conductivity of the backfill.

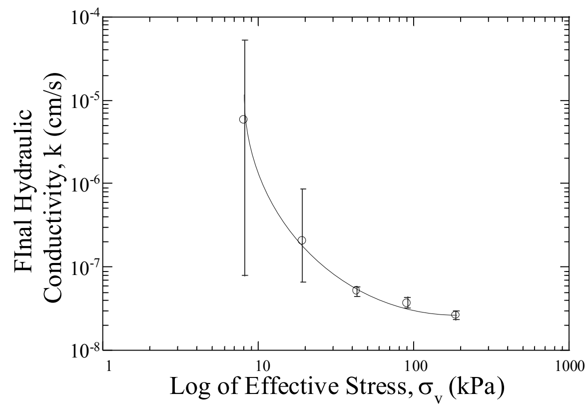


Fig. 3 Results of Hydraulic Conductivity Tests

The procedures used to determine the shear strength of the SB backfill from the raw data collected during each of these tests can be found in Ruffing (2009).

Figures 4, 5, and 6 show the shear strength values predicted from the CPT results (using two different correction factors called N-values), VST, and DMT, respectively, during construction, and after the wall had aged 3, 6, and 9 months. The first N-value was chosen based on recommendations in Powell and Lunne (2005). The second was predicted using the vane shear results of this study.

Monitoring wells installed inside and outside of the wall were used to determine the effectiveness of the wall to slow groundwater migration into the site. Figure 7 shows the measured water levels inside and outside of the wall at the times that the field tests were conducted.

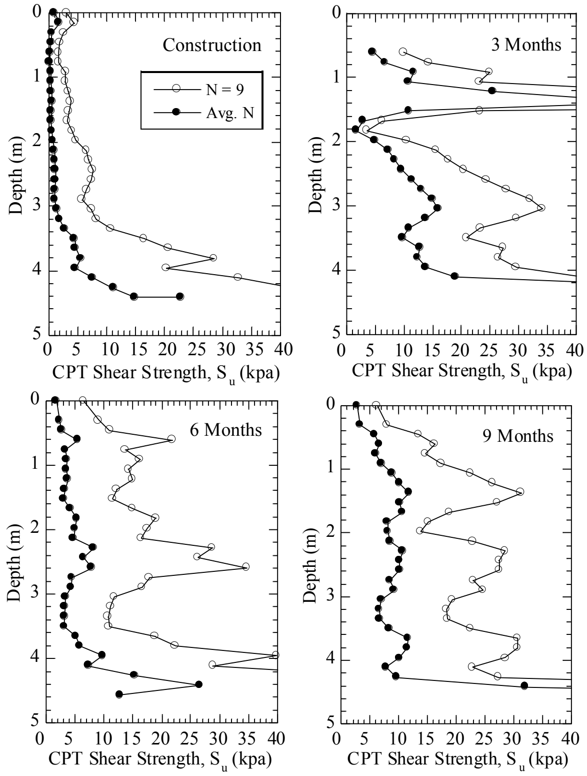
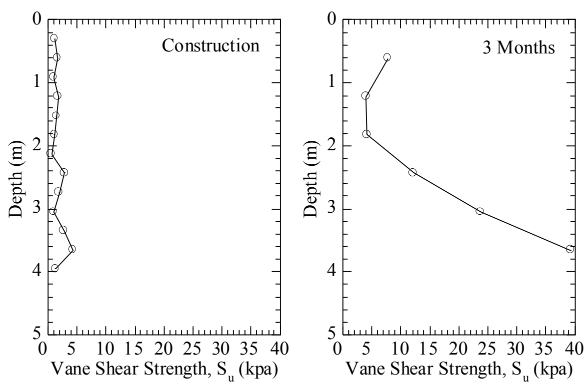


Fig. 4 Shear Strength from CPT vs. Depth



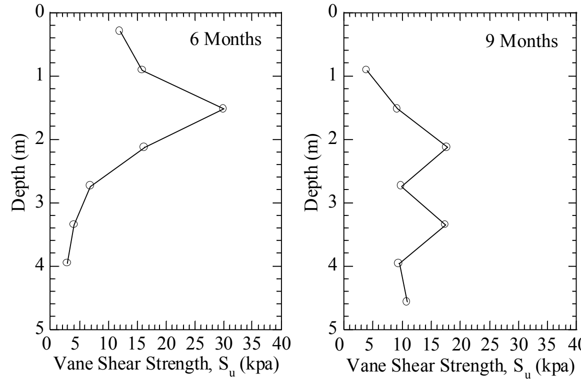


Fig. 5 Shear Strength from Vane Shear vs. Depth

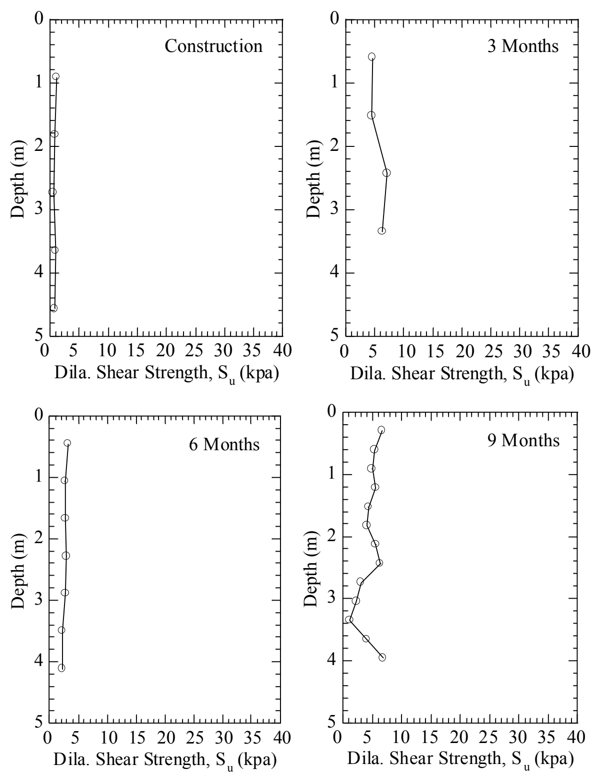


Fig. 6 Shear Strength from Dilatometer vs. Depth

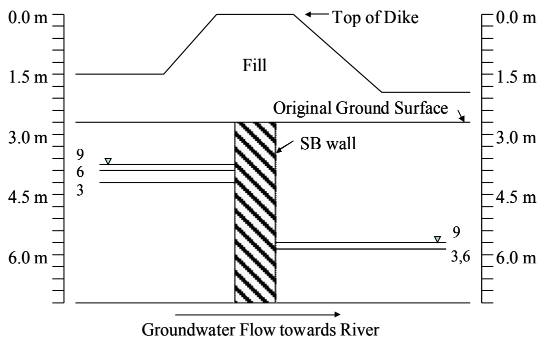


Fig. 7 Groundwater levels at 3, 6, 9 months

DISCUSSION OF RESULTS

The grain size distribution, Atterberg limits, moisture content, and classification all confirm that the SB backfill at this site is typical of a well graded SB backfill. The compression index and modified compression index were both within the ranges found in the literature for SB backfill (Yeo et al. 2005, Barben 2008). Thus the backfill is representative of a typical SB slurry trench cutoff wall backfill.

The rigid wall permeability results were consistent with trends presented in previous studies (Evans 1994, Filz et al. 2001, Yeo et al. 2005) in that the hydraulic conductivity decreased with increasing effective stress. Additionally, these data revealed decreasing variation in the hydraulic conductivity with increasing effective stress. In order to meet this project's permeability requirement a soil element would need to have a confining stress equal to or greater than 20 kPa.

While there is significant variation in the shear strength values found during this study, the data does show a slight increase in shear strength with time and depth, but not significant as expected under normal geostatic consolidation of a soft clayey material. This lack of significant consolidation is likely due to arching forces limiting stress development in the backfill (Kezdi 1975, Evans et al. 1995). However, the data collected in this wall is challenged due to 1. the shallow depth of the wall, 2. the presence of large rocks in the SB backfill, and 3. the placement of an earthen embankment over the wall at a time between the end of construction and the testing conducted after the wall had aged 3 months. While geosynthetics were used at the base of the dike to span the trench, it is possible that the shear strength gain exhibited in the CPT and DMT data between construction and 3 months was influenced by the placement of the earthen embankment rather than self-weight consolidation of the backfill. The vane shear strength at 3 months is inconsistent with all other strength data and is considered anomalous. These results could be caused by the large rocks in the backfill or possibly because the vane had strayed into the sidewall of the trench. The wall's shear strength at all ages and depths classifies the wall as a very soft material (Terzaghi and Peck 1967).

The measured groundwater levels indicate that the barrier wall is performing its intended task. The groundwater level measured outside of the wall was consistently higher than that measured on the inside at all ages of the wall.

CONCLUSIONS

SB cutoff walls are widely employed in the US for the *in situ* containment of groundwater and contamination. The mechanisms that control stress development in these walls are not well understood and a limited number of field studies have been conducted to confirm the results of the large laboratory research effort that has been devoted to these walls. The paucity of field testing leads to a gap in the understanding of how these walls behave on a macro scale. The wall in Birdsboro, PA provided a unique opportunity for research, but was limited by its shallow depth. The findings of this study demonstrated that the hydraulic conductivity decreases as the effective confining stress increases, even at the low stress ranges found in these walls. The shear strength measured using three different field investigation tools indicated that there may be some consolidation soon after construction, but the backfill does not show any significant change in shear strength beyond this initial gain. Despite the likely low effective stress in the backfill, the wall appears to be behaving as intended as evidenced by the noticeable difference between the groundwater level measured inside and outside of the wall.

ACKNOWLEDGEMENTS

Financial support for this work was provided, in part, by the National Science Foundation (NSF) through Grant No. CMMI-0722584. The opinions and recommendations in this paper are solely those of the authors and are not necessarily consistent with the policies of NSF. The authors would also like to thank the municipality of Birdboro, PA for allowing the research and Brent Estock for coordinating the access to the site. Additionally, the authors would like to thank Jim Gutelius for the time and effort that he put into making this research a reality.

REFERENCES

ASTM D2435-04, Standard test methods for one-dimensional consolidation properties of soils using incremental loading. ASTM International, West Conshohocken, PA.

ASTM D2487-00, Standard classification of soils for engineering purposes (Unified Soil Classification System). ASTM International, West Conshohocken, PA.

ASTM D2573-01 Standard Test Method for Field Vane Shear Test in Cohesive Soils. ASTM International, West Conshohocken, PA.

ASTM D422-63, Standard test method for particle-size analysis of soils. ASTM International, West Conshohocken, PA.

ASTM D4318-05, Standard test methods for liquid limit, plastic limit, and plasticity index of soils. ASTM International, West Conshohocken, PA.

ASTM D5778-07, Standard Test Method for Mechanical Cone Penetration Test of Soils. ASTM International, West Conshohocken, PA.

ASTM D6635-01 Standard Test Method for Performing the Flat Plate Dilatometer. ASTM International, West Conshohocken, PA.

Barben, E.J. (2008) Enhanced Clay Barriers: Soil-Bentonite Cutoff Wall Backfill Amended with Activated Carbon. MS thesis, Dept. of Civil and Env. Engineering, Bucknell Univ., Lewisburg, PA.

Evans, J.C., (1994). "Hydraulic conductivity of vertical cutoff walls." *Hydraulic Conductivity and Waste Contaminant Transport in Soil*, *ASTM STP 1142*, 79-94.

Evans, J.C., Costa, M.J., and Cooley, B. (1995). "The state of stress in soil-bentonite slurry trench cutoff walls." *GSP No. 46*, ASCE, Reston, VA: 1173-1191.

Filz, G.M. (1996). "Consolidation stresses in soil-bentonite back-filled trenches." *Proc., 2nd Int. Congress on Env. Geotechnics,* M. Kamon, Ed., Osaka/Japan, 497-502.

Filz et al. (2001). "Determining hydraulic conductivity of soil-bentonite using the API filter press." *ASTM Geotechnical Testing Journal*, v. 24, no. 1, pp 61-71.

Kezdi, A. (1975). "Lateral Earth Pressures." in *Foundation Engineering Handbook*, Von Nostrand Reinhold, Winterkorn H.F. and Fang, H.Y., eds.

National Research Council (2007). *Assessment of the Performance of Engineered Waste Containment Facilities*, National Academics Press, Washington/DC: 121 p.

Powell, J., and Lunne, T., (2005) "Use of CPT Data in Clays/Fine Grained Soils." *Studia Geotechnica et Mechanica,* Vol. XXVII, No. 3-4, 53-63.

Ruffing, D.G., Evans, J.C. and Malusis, M.A., (2010). "Prediction of Earth Pressures in Soil-Bentonite Cutoff Walls" GeoFlorida 2010, *GSP No. 199*, ASCE, Reston, VA.

Ruffing, D. (2009). A reevaluation of the state of stress in soil-bentonite slurry trench cutoff walls. MS thesis, Dept. of Civil and Environmental Engineering, Bucknell Univ., Lewisburg, PA.

Schmertmann, J.H. (1988). "Guidelines for Using the CPT, CPTU and Marchetti DMT for Geotechnical Design". Rept. No. FHWA-PA-87-022+84-24 to PennDOT, Office of Research and Special Studies, Harrisburg, PA, in 4 volumes with the 3 below concerning primarily the DMT: Vol. III - DMT Test Methods and Data Reduction (183 pp.)

Terzaghi, Karl, and Ralph B. Peck. (1967). Soil Mechanics in Engineering Practice, International Edition. A Wiley

Yeo, S.-S., Shackelford, C.D. and Evans J.C. (2005) Consolidation and Hydraulic Conductivity of Nine Model Soil-Bentonite Backfills. *J. Geotech Geoenv. Eng.* 131 (10), 1189-1198.