SERRI Report 70015-007

DEWATERING SOIL FOR USE AS AN EMERGENCY CONSTRUCTION MATERIAL FOR DISASTER RECOVERY

SERRI Project: *Increasing Community Disaster Resilience Through Targeted Strengthening of Critical Infrastructure*

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16. Abstract

The objective of this report was to investigate means to rapidly dewater fine grained soils for immediate re-use as an emergency construction material. Dewatering using polymers was the primary thrust of the research. Secondary efforts were related to the use of geotextile tubes and equipment such as clarifiers to expedite dewatering of fine grained soil for immediate re-use as an emergency construction material. The dewatered soils are to be stabilized with cementitious materials prior to use, which is also addressed in this report. Test results indicated the approach was feasible, yet not the most practical approach for development of an emergency construction material. The research indicated emergency dewatering of contaminated sediments to be a more suitable application. Factors leading to this decision were largely related to portable equipment availability and polymer supply/demand in a disaster environment. Settling column testing incorporating polymers provided promising results and indicated polymer dosage requirements could be lessened for this application relative to optimum rates found from gravity flow drainage testing.

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Mr. Ed Trainer of *Tencate™ Geotube®* provided significant in-kind support to this project. Donation of *Geotube®* dewatering test specimens and providing in-kind technical assistance were notable contributions made by Mr. Trainer that are greatly appreciated. Mr. Trainer has also been invaluable to this and other research reports conducted by the research team for the *SERRI* program under project 70015.

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SYMBOLS AND ACRONYMS

A	total area of geosynthetic
AOS	apparent opening size of geotextile
A_1	area of column
A_2	area of exit
D	polymer dosage rate expressed as kg of polymer per dry metric ton of soil
DHS	Department of Homeland Security
D_{int}	distance from geotextile/soil interface (mm)
D_{10}	diameter where 50% of soil passes
D_{50}	diameter where 50% of soil passes
D_{90}	diameter where 90% of soil passes
D_{95}	diameter where 95% of soil passes
GDT	*Geotube*® dewatering test
G_s	specific gravity of solids
LL	liquid limit
MSU	Mississippi State University
NTU	Nephelometric Turbidity Units
ORNL	Oak Ridge National Laboratory
O_{50}	opening where 50% of soil passes
O_{95}	opening where 95% of soil passes
PL	plastic limit
Q	flow rate entering clarifier (Lpm)
S_c	solids content or percent solids (by mass)
SERRI	Southeast Region Research Initiative
SG_{slurry}	specific gravity of slurry
SS	suspended solids
$TS_{\%}$	total solids by weight expressed as a percentage
$TS_{(V)\%}$	total solids by volume expressed as a percentage
$TS_{\%\text{-}In}$	total solids expressed as a percent entering clarifier
UC	unconfined compression test
USACE	United States Army Corps of Engineers
USCS	Unified Soil Classification System
V_1	velocity of material while in column
V_2	velocity of material while exiting column
V_v	volume of voids
V_s	volume of solids
V_p	volume of polymer solution
V_F	total volume of filtrate
V_{FN}	net volume of filtrate ($V_F - V_p$)
V_{20}	settling velocity at 20 sec
V_{50}	settling velocity at 50 sec
V_{90}	settling velocity at 90 sec
W_{dist}	water content at D_{int}
W_{int}	initial water content of slurry

cov	coefficient of variation
d_{iaca}	diameter of contact area (mm)
e	void ratio
k_n	hydraulic conductivity normal to geotextile
k_o	coefficient of earth pressure at rest
m_a	mass of wet sample
m_b	mass of dry sample
n	number of data points considered in analysis
ppm	polymer dosage rate in parts per million in relation to the original slurry
pillow	scaled *Geotube*® made from *GT 500* geotextile
q	flow rate
s_u	undrained shear strength
$t_{\Delta t}$	time where maximum temperature difference occurs in a stabilized slab
w_{se}	weight of solids exiting clarifier (metric tons per hour)
$w_{\%}$	moisture content expressed as a percentage
w_w	weight of water
w_s	weight of solids
γ_w	unit weight of water (kg/liter)
ψ	permittivity (s^{-1})
ΔT	change in temperature within stabilized slab with room temperature reference
Δh	head loss

CHAPTER 1 - INTRODUCTION

1.1 General and Background Information

The work presented in this report was developed in partial fulfillment of the requirements of Task Order 4000064719 sponsored by the *Department of Homeland Security (DHS)* through its *Southeast Regional Research Initiative (SERRI)* program administered by *UT-Battelle* at the *Oak Ridge National Laboratory (ORNL)* in Oak Ridge, Tennessee. The research was proposed by members of the *Department of Civil and Environmental Engineering (CEE)* at *Mississippi State University (MSU)* to *SERRI* in a document dated 1 June 2007. The proposed research was authorized by *UT-Battelle* in its task order dated 10 December 2007. This task order included a scope of work defined through joint discussions between *MSU* and *SERRI*. Work on the project was initiated on 1 January 2008. A modification of Task Order 4000064719 was proposed on 9 September 2008 and agreed upon on 29 September 2008. A second Task Order modification dated 22 June 2010 was also performed, which is the Task Order used to generate this report.

The scope of work associated with Task Order 4000064719 included several related components. The general objectives of the project were to investigate means for rapidly using on-site materials and methods in ways that would most effectively enable local communities to rebuild in the wake of a flooding disaster. Within this general framework, several key work components were associated with Task Order 4000064719. Specifically, the scope of work dated 22 June 2010 includes research efforts in the following six task groups:

Task 1: Erosion Control-Erosion Protection for Earthen Levees.

Task 2: Bridge Stability-Lateral & Uplift Stability of Gravity-Supported Bridge Decks.

Task 3: Levee Breach Repair-Closure of Breaches in Flood Protection Systems.

Task 4: Pavement Characterization and Repair.

Task 5: Emergency Construction Material Development-Staging Platform Construction.

Task 6: Fresh Water Reservoir-Restoration of Fresh Water Supplies.

The division of the research effort allowed the work to be broken into manageable portions so that key components could be reported in separate volumes to allow readers to obtain only the work related to their needs. The work contained herein was associated with Task 5. The report of this work was the 7th deliverable of the research project, hence the designation of the report as *SERRI Report 70015-007* of Task Order 4000064719. Work related to Task 5 was also submitted in *SERRI Report 70015-006 and SERRI Report 70015-008;* these three reports represent full completion of Task 5.

1.2 Objectives

The general objective of Task Order 4000064719 was to investigate several specific means by which local communities may best use available resources in an effort to rapidly recover from a flooding disaster. In the wake of a flooding disaster, this broad objective would include rebuilding a community with the efforts of a variety of professionals practicing within the physical and social sciences. The research conducted was much more narrowly focused upon certain recovery efforts typically associated with Civil Engineering.

A key component of this research was to develop solutions which may be rapidly deployed to achieve maximum benefit to the community, typically through the use of on-site materials, pre-engineered components, and innovative construction materials and techniques. This research aimed to develop solutions for protecting and/or expeditiously reconstituting critical civil infrastructure components. The research emphasized rapid constructability where existing on-site materials are used to strengthen selected infrastructure components. In this context, the specific objective of the total effort of Task Order 4000064719 was to develop specialty materials and design and construction procedures which may be rapidly deployed to protect and restore selected key civil infrastructure components. Combinations of dredging equipment, small barges, excavating equipment, positive displacement pumps, and soil mixing devices were investigated in terms of their ability to assist in construction of essential temporary infrastructure out of controlled low strength materials.

The primary objective of the research presented in this report was to develop methods to rapidly dewater dredged soil for immediate use as an emergency construction material. The research presented serves as a compliment to the larger task of developing an emergency construction material by stabilizing soils using specialty cementitious blends. Within the primary objective, it was the intent of the research performed within this report to assess feasibility of rapidly dewatering soil for use as an emergency construction material and develop laboratory properties for candidate soils.

1.3 Scope

For the specific research component described in this report (Task 5), the revised scope of work dated 22 June 2010 includes nine items. These nine items are the full deliverable of Task 5; this report fully addresses item d). *SERRI Report 70015-006* fully addresses items a), b), c), e), and f), while partially addressing items h) and i). *SERRI Report 70015-008* fully addresses item g) and addresses the remainder of item h). *SERRI Report 70015-003* addresses the remainder of item i).

a) Acquire representative material for testing from locations that would be candidates for flooding (e.g. New Orleans and Mobile). The origin of the material will vary from dredging operations to native soils in these types of areas, and will be used throughout testing. Where applicable in-situ moisture contents will be obtained to provide a baseline of properties. Large quantities of three soils will be obtained with varying plasticity and organic content.

b) Characterize basic properties of materials. Testing will be performed to measure: 1) Activity (ASTM D 422), 2) Organic Content (ASTM D 2974 or equivalent), 3) Atterberg Limits (ASTM D 4318), 4) Specific Gravity (ASTM D 854), 5) USCS Classification (ASTM D 2487), 6) Particle Size Distribution (ASTM D 422), 7) XRF, and 8) pH.

c) Develop a comprehensive suite of load response properties with time for the soils described in a) using bench scale testing. The testing protocol will consist of shear strength testing of prepared stabilized slurry slabs and unconfined compression testing as appropriate. Very thin membranes will also be tested in conjunction with the materials. Both types of testing will be intended to simulate shear strength of the stabilized slurries with time over a period of seven days. The aforementioned test protocol was selected for two reasons. The slab testing method will be developed in a manner that will be applicable to on site responders, which makes it highly desirable. The stabilization materials to be blended with the candidate soils include: 1) *Type I* portland cement from both the major types of cement plants, 2) *Type III* portland cement from both major types of cement plants, 3) commercially available rapid set cement, 4) six specialty cements produced specifically from this research (four by interrupting normal production at both major types of portland cement plants and two blended calcium sulfoaluminate cements), 5) ground granulated blast furnace slag, and 6) two types of polymer fibers. This materials protocol includes 14 different stabilization additives encompassing a wide variety of properties. Development of the specialty cements will be performed using laboratory testing including semi-adiabatic calorimetry.

d) Investigate dewatering equipment and materials for applicability in disaster environments, in particular to assist in development of emergency construction materials with secondary emphasis in handling contaminated sediments. The investigation will focus on the use of polymers for dewatering a soil mass and also investigate geotextile tubes. A test environment will be developed where a series of potentially applicable polymers will be tested (in conjunction with scaled geotextile tubes in some instances as appropriate) to determine if the technology can produce sufficient material at an acceptable moisture content for large scale emergency construction material needs. Moisture content variability conditions will also be investigated in the context of dewatering. The effect of dewatering polymers on shear strength in the presence of multiple cements will also be investigated via slab and unconfined compression techniques.

e) Select cementitious materials investigated in the bench scale study c) will be further investigated in a mixing (or blending) study to evaluate effect of key parameters. Examples of key parameters would be cementitious sulfate content and its effect on shear strength and the effect of blending ground granulated blast furnace slag with portland cement in high moisture content fine grained soils.

f) Test the behavior of multiple cement blends (selected from the 14 original blends previously mentioned) in the presence of brackish water and seawater. Testing will be performed via slab and unconfined compression techniques. The bench and mixing studies only incorporate fresh (tap) water. A final blend will be selected for each soil type and set of conditions at the conclusion of this subtask considering all knowledge gained from subtasks a) to f).

g) Develop design and construction guidance (e.g. identifying suitable applications and providing placement and mixing approach) for using the emergency construction material blends developed at the conclusion of subtask f). Use of the material for the purpose of developing a staging platform will be highlighted. Strength and stiffness of the materials developed will be incorporated into the staging platform guidance (e.g. ability of staging platform to support helicopter loads and/or support freight lowered onto platform from a helicopter).

h) Design and construction procedures using the emergency material will be highly dependent upon the stabilized soil blend achieving a given set of properties with time. For this reason, hand held field shear strength measurement devices will be evaluated statistically for the purpose of assessing risk associated with strength gain measurement over time (precision, accuracy, and repeatability are envisioned to be the focus of the assessment). The results of the hand held gage assessment could be used on site to quantify the impacts of equipment malfunctions, lack of personnel, or other events on the stability of the constructed platform or other structure.

i) Test material obtained from construction site visits in unconfined compression to provide a comparison of the properties of the stabilized blends made from materials obtained in subtask a). It is anticipated that test results will be obtained from three to five sites.

The research team firmly held the position that industry participation was key to a successful end product. To this end, multiple private industries and related entities were contacted to assess their expertise and ability to further the project. Response to a water based disaster must have a strong industrial (i.e. private sector) component to be successful.

This document (*SERRI Report 70015-007*) is the second of the three reports of Task 5. This report aims to provide guidance for rapidly dewatering soil. *SERRI Report 70015-006* provided guidance in developing the emergency construction material (which may require dewatering using the techniques of this report). Once the construction material has been developed, design and construction guidance is provided in *SERRI Report 70015-008*; the example use of a staging platform is the focus. *SERRI Report 70015-006* included how Task 5 as a whole fits into disaster recovery (e.g. *National Response Framework*), which is omitted from this report.

Assessment of filtrate clarity was not considered in this research. The fate of filtrate discharges generated by settling and/or dewatering is regulated under the auspices of a state-issued discharge permit under non-emergency conditions. It is unknown how potentially affected states would view the discharge with respect to aquatic toxicity and environmental impact in a disaster environment.

1.4 Terminology Used Within Report

The research conducted within Task 5 crosses multiple disciplinary lines (geotechnical engineering, water resources engineering, manufacturing, and polymer science), which makes a clear understanding of terminology essential. Slurries can be characterized by solids content (Eq. 1.1). As dewatering occurs and noticeable amounts of soil particles come in contact with each other, description of the material in many applications is performed using the void ratio (Eq. 1.2). The *American Public Health Association* defines suspended solids as per Eq. 1.3, which can also be used for slurry characterization.

$$S_c = \frac{SG_{slurry}}{e + SG_{slurry}} \tag{1.1}$$

$$e = \frac{V_V}{V_S} \tag{1.2}$$

$$SS = \frac{m_b}{(m_a - m_b) + m_b / G_s} \tag{1.3}$$

Where,

S_c = Solids content or percent solids (by mass)
SG_{slurry} = Specific gravity of slurry
e = Void ratio
V_V = Volume of voids
V_s = Volume of solids
SS = suspended solids
m_a = mass of wet sample
m_b = mass of dry sample
G_s = specific gravity of solids

Geotechnical engineers often reference dry solid weight when presenting a moisture condition (Eq. 1.4). Dredging and water resources often reference total weight when presenting a moisture condition (Eq. 1.5) and refer to the term as total solids or solids content, while they also reference volume when reporting a moisture condition in some cases (Eq. 1.6). Permittivity is a common term used in the context of dewatering coupled with geosynthetics (Eq. 1.7).

$$w_{\%} = \frac{w_w}{w_s}(100) \tag{1.4}$$

$$TS_{\%} = \frac{w_s}{w_w + w_s}(100) = \frac{w_w / w_{\%}}{w_w + w_s}(100^2) \tag{1.5}$$

$$TS_{(V)\%} = \frac{V_s}{V_w + V_s}(100) \tag{1.6}$$

$$\psi = \frac{k_n}{t} = \frac{q}{\Delta h(A)} \tag{1.7}$$

Where,

$w_{\%}$ = moisture content expressed as a percentage
w_w = weight of water (g)
w_s = weight of solids (g)
$TS_{\%}$ = total solids by weight expressed as a percentage
$TS_{(V)\%}$ = total solids by volume expressed as a percentage
ψ = permittivity (s^{-1})
k_n = hydraulic conductivity normal to geotextile
q = flow rate
Δh = head loss
A = total area of geosynthetic

CHAPTER 2 – LITERATURE AND PRACTICE REVIEW

2.1 Overview of Literature and Practice Review

Haliburton (1977) indicated fine grained cohesive dredged material near fully consolidated by self weight reached an equilibrium moisture content noticeably above the liquid limit with a consistency resembling warm axle grease. Dewatered solids can reach 70% total solids by weight, though this takes considerable time. The objective of the literature and practice review was to identify equipment, techniques, and materials to allow $TS_{\%}$ values to be increased from 10 to approximately 30.

In standard dewatering practice, the relationship between cake dryness and transportation cost is non-linear (Englis and Hunter 2008). During early stages, transportation costs are significantly reduced, but the rate of reduction greatly slows as the percent solids increase. Removal of water in the range where the greatest ease occurs coupled with cementitious material quantities and construction equipment was a major focus of this research. Removal of water was the focus of this report, while the majority of the equipment considerations necessary to develop an emergency construction material are described elsewhere.

2.2 Dewatering Polymers

Polymer treatment can be effective on all particles smaller than 75 μm including cohesive sediments (< 62.5 μm), suspended solids (< 45 μm), and colloidal particles (< 1 μm). According to Hunter et al. (2006), the following characteristics make materials amenable to polymer treatment: 1) particles smaller than 75 μm; 2) high organic content; and 3) high mass to surface ratio of individual particles. The rate of settlement is directly dependent on particle size. To settle a distance of 1 m without polymer treatment, the time can vary from a few seconds for gravel to hundreds of hours for larger clay particles and to years for colloids (0.01 μm).

Dewatering soil is performed primarily through two mechanisms: coagulation, and flocculation. Soil particles less than 75 μm tend to attract electrical charge of similar characteristics that cause the particles to repel one another and inhibit gravitational forces causing settlement. Coagulants affect these charges and thus induce agglomeration (i.e. clustering) to occur relatively rapidly. Flocculants have high molecular weight and attract oppositely charged particles to sites that have been charged along the length of its chain, which is relatively long. The result is an aggregate of material held together by the long thread like structures that link the particles and thus induce settlement out of suspension. In the case of flocculation, the particles themselves are not usually in contact, rather they are connected through the polymers. Coagulants typically connect the particles directly.

Coagulants and flocculants are different in chemical composition and process. Coagulants typically have a low molecular weight of $0.1(10^6)$ to $1.0(10^6)$ atomic mass units (amu) and a high charge density of 6 to 7 milli-equivalents per gram of sorbing material (meq/g). Flocculants typically have a molecular weight of $3(10^6)$ to $15(10^6)$ amu and a variable charge density. Coagulants lack the molecular weight to effectively initiate flocculation, but flocculants can be developed in a full range of molecular weights and charge densities so they can (and in many cases do) flocculate and coagulate particles. The overall treatment plan used on a given soil should include carefully selected amounts of coagulation and flocculation to achieve the desired results; this may require multiple polymers to be used.

A polymer can be non-ionic, anionic, or cationic. Coagulants are cationic and reduce electrostatic forces to allow agglomeration. Bonds created by coagulation can be broken during solids dewatering due to excessive shear force, which allows re-suspension of the solids. Flocculants can have any charge. Figure 2.1 provides a visual summary of selection of polymers for water treatment. The bottom quadrant materials are not of interest for this research.

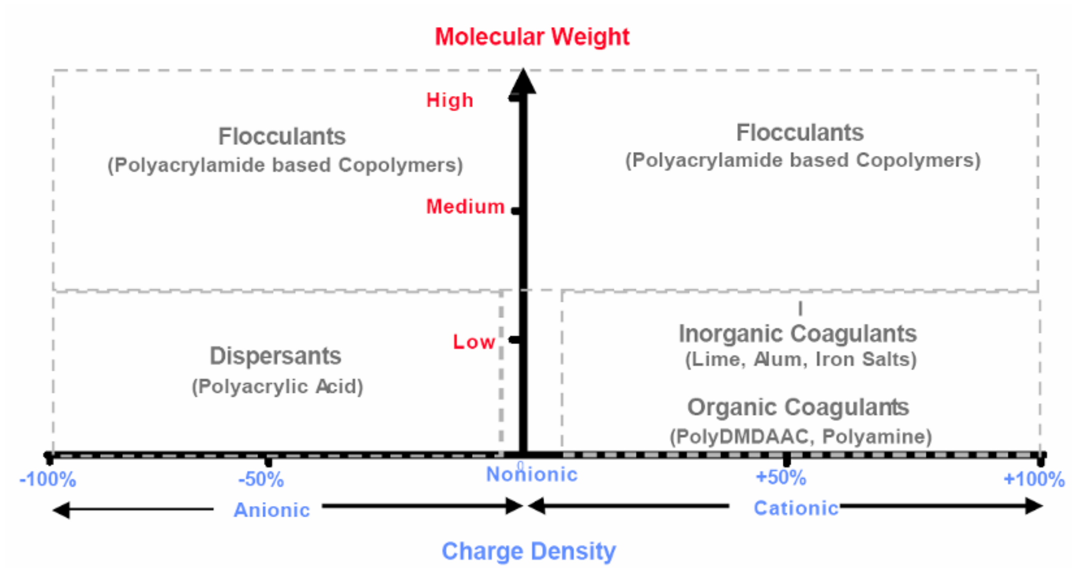


Figure 2.1. Chemical Characteristics of Polymers from Hunter et al. (2006)

Metal ions have been shown to affect coagulation and flocculation. Soil compositions can provide metal ions effective in assisting coagulation of clays (MacDonald et al. 2009). The addition of metal ions enhanced flocculation performance by dramatically reducing the magnitude of the particle zeta potential (McFarlane et al. 2005; McFarlane et al. 2006).

Most polymer incorporated into dredging projects occurs within upland disposal operations or solids dewatering operations (Hunter et al. 2006). Multiple dredging projects have used polymers. Low cationic medium to high molecular weight often works well for river and lake sediments. Hunter et al. (2006) describes five such projects; four of them utilized automated polymer dosage control to adjust for fluctuations occurring due to incoming slurry concentrations and slurry flow variations. The automated systems minimized polymer dosages.

Figure 2.2 shows an example polymer dewatering system used to place treated slurry into a *Geotube*® unit with key components labeled. Figure 2.3 is an example flowchart showing key equipment and procedural components of a typical dewatering system. Note the solid black line is an enclosed system, which is shown in Figure 2.4. The fully enclosed liquid polymer make down system shown in Figure 2.4 was developed by *Ciba Corporation*.

The system shown has dimensions of 6.1 by 2.4 by 2.4 m tall, weighs 3,700 kg, and requires a 380 Lpm water supply delivered at a pressure of 275 kPa. A 100 kW generator is also required external to the system as seen in Figure 2.3. A complimentary system using dry polymers had not been completed as of October 2008; it is expected to be larger than the liquid polymer trailer.

Figure 2.2. Example Polymer Dewatering System

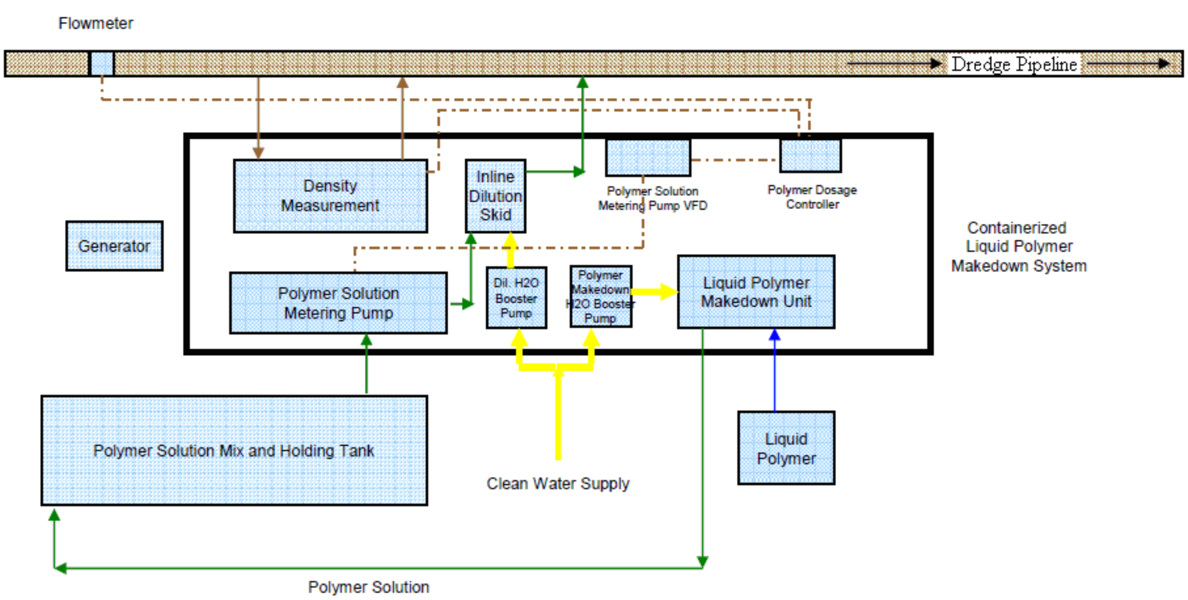


Figure 2.3. Example Dewatering System Layout from Howard et al. (2009)

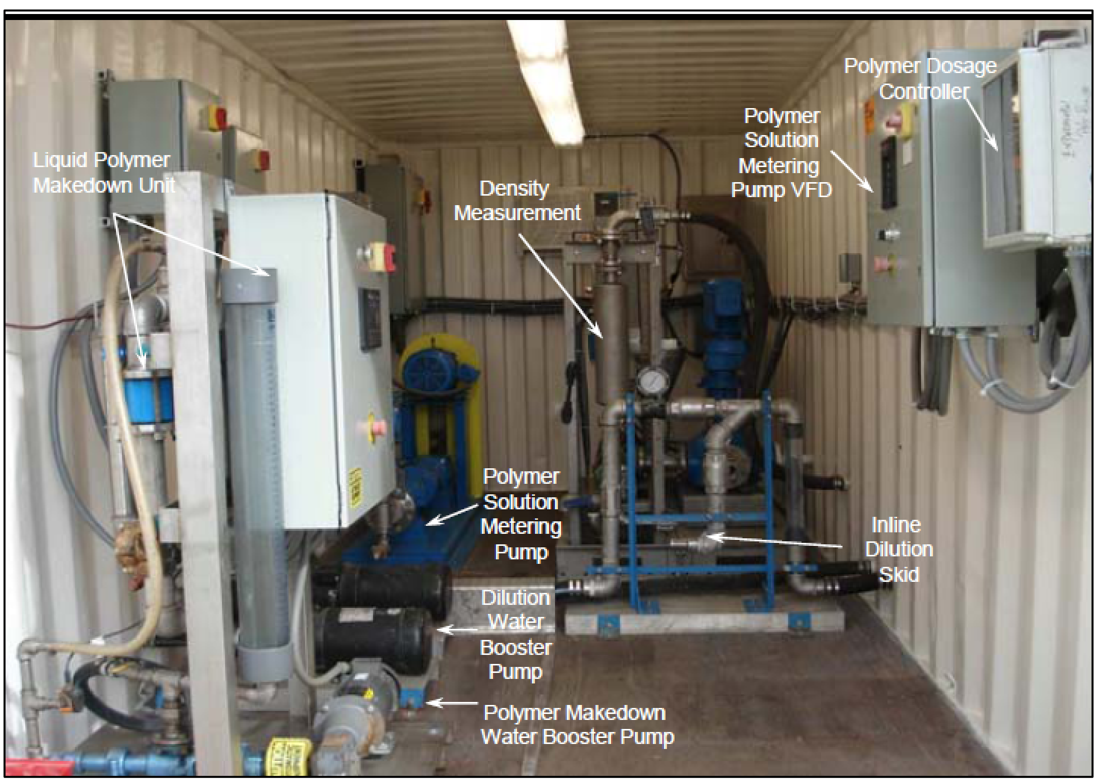
In October of 2008, *Ciba Corporation* owned two liquid polymer trailer units; depending on timing they might or might not be available for use in a disaster. Dedicated trailer units may be necessary. Conversation with *Ciba* technical personnel at their facility in

October of 2008 indicated that polymer equipment probably won't be the biggest challenge and that the equipment could be manufactured fairly quickly.

Mixing of polymers in line is extremely important to ensure attachment to solid particles. A polymer cannot simply be placed in the top of a large volume of material. To mix the polymer into the soil slurry at full scale, 90-degree elbows in close succession (e.g. three elbows in 1 m) are often used to induce turbulent flow in the delivery line. Polymer is typically injected at four locations around the perimeter of the inlet pipe to facilitate mixing with the slurry. Also note polymers should be made into solution and aged 30 minutes prior to use.

(a) Loading System onto Trailer

(b) Trailer Being Transported



(c) Inside View of Trailer

Figure 2.4. Ciba Containerized Liquid Polymer Make Down System

As described by Englis and Hunter (2008), flow rates and slurried solids concentrations are subject to frequent and rapid changes. Automated equipment that can sample the slurry, sense changes in density and flow rates, and automatically adjust the chemical dosage through a computer interface is the most desirable approach. In practice, when the slurry flow rate is relatively constant, the density is often used to adjust the dosage rate in the measurement and control feedback loop, and the dosage rate changes on a regular basis. The variability in dosage rate can be quite large.

Shear forces must also be considered when selection of a conditioning program and dosage requirements. The primary factor in selection of chemical quantities is the solids concentration, but the shear forces to be imposed can also be noteworthy in that at elevated levels they can cause the need for additional polymer. The concern of the shear forces is they can break bonds and place particles back in suspension. Shear forces are relatively low in geotextile tubes, which in turn makes the amount of polymer dosing relatively less.

Table 2.1 contains data from dredging and dewatering projects provided by *Ciba*. Of particular note is the quantity of polymer delivered per day of construction. Ciba's largest system (non-containerized) can supply 114 kg of active polymer per hour, while the containerized system of Figure 2.4 can supply 47 kg of active polymer per hour. The units are fully automated and could function 24 hours a day. Prices of polymers applicable to this research in October of 2009 were on the order of \$2.75 to \$4.50 per kg of active polymer for typical applications, supply conditions, and similar.

Table 2.1. Dredging and Dewatering Projects Provided by *Ciba Corporation*

Project	In-Situ[1] (m^3)	In-Situ[2] (DT_m)	Flow (Lpm)	Polymer Type	Rate[3] (kg/DT_m)	Quantity[4] (kg/day)	Time Est. (days)
1	8411	1148	3028	Liquid	1.5	330	15
2	55051	3374	3785	Liquid	4.5	869	50
3	12616	2438	3785	Liquid	3.5	1138	15
4	7646	6783	3785	Liquid	0.3	81	50
5	9175	9841	5072	Dry	0.8	84	88
6	120807	61333	5072	Dry	1.3	767	100
7	103986	45560	4542	Dry	0.9	387	100
8	103986	45560	4542	Dry	0.9	387	100
9	22938	11647	4542	Dry	1.4	615	26

1: Total in-situ material to be dewatered.
2: Total in-situ dry tons to be dewatered.
3: Active dosage rate.
4: Quantity does not account for inactive materials for liquid polymers.

Clearwater Industries also manufactures portable dewatering units. The *Model 500* can supply 31 kg of active polymer per hour if a 0.5% solution is aged 30 minutes (ideally a solution of 0.2 to 0.3% is used in conjunction with a 45 minute aging). Under the same constraints, the *Model 800* can supply 62 kg of active polymer per hour. The *Model 3000* could conceivably supply in excess of 150 kg under these circumstances, but it is not highly portable. The *Model 500* and *Model 800* can be operational within one hour of arrival to the site. The *Model 500* has dimensions of 1.52 by 2.90 by 2.13 m tall, weighs 700 kg empty, and weighs 3,800 kg during operation. The *Model 800* has dimensions of 1.83 by 4.37 by 2.52 m tall, weighs 1,150 kg empty, and weighs 6,250 kg during operation.

There are a wide variety of chemical additives available, so the selection of the best chemical for a given substrate is non-trivial and requires consultation with knowledgeable personnel. Industry dewatering experts caution against over generalization, especially over long periods of time. Polymer chemistry and technology can change radically over a period of several years. All polymers are not created equally. Each substrate must be assessed based on its own merit. The chemical treatment is greatly enhanced by tailoring it to the application. Interaction with a polymer company with knowledge of all facets of the process is needed for optimal results. When using polymers, they must be properly matched to the sediment being treated. Over polymerization can blind dewatering fabrics. Plots of floc size versus dosage rate are not necessarily consistent between material types. In some cases, the plot reaches a plateau, others break slightly, while others break drastically over a threshold dosage rate. Contaminated sediment can affect polymer treatment.

Ciba Water Solutions division carries four primary groups of products: 1) ZETAG®; 2) MAGNAFLOC®; 3) MAGNASOL®; and 4) KRYSALIS®. KRYSALIS® are a range of products designed for solid-liquid separation within the dredging industry applicable to this research. These are synthetic, water soluble polymers (of primary interest herein) that contain organic repeating single monomer units of carbon-based molecules linked together to form long chained compounds. Molecular weight is essentially the length of the chain and the longer the polymer chain the higher the relative molecular weight. Monomers of either cationic (+), anionic (-), or neutral charge are reacted with these compounds. In general, a cationic charge is kept as low as possible; otherwise toxicity can be an issue. The final product is referred to in water chemistry as a synthetic organic polyelectrolyte. The environmental safety in terms of ecotoxicity of the product has been demonstrated on multiple occasions but note that the different versions of KRYSALIS® have different ecotoxicity properties. The materials are biodegradable but the process is slow.

Polymer dosage is usually expressed in one of two manners. The first is a weight-to-weight ratio of kg (lb) of polymer in its as-supplied form per dry metric ton (ton) of dredged slurry dry solids. The second is in parts per million (*ppm*) in relation to the original slurry prior to dewatering, which is related to a weight to weight dosage rate by Eq. 2.1.

$$ppm = 10\left(TS_{\%}\right)\left(D\right) \qquad (2.1)$$

Where,

ppm = polymer dosage rate in parts per million in relation to the original slurry
D = polymer dosage rate expressed as kg of polymer per dry metric ton of soil, or kg/DT_m

Multiple entities were contacted to obtain an assessment of dosage rates for a variety of conditions; Table 2.1 also provided data from multiple projects. For highly plastic materials (often organic), dosage rates in excess of 1,000 *ppm* have been required. For $TS_{\%}$ of 10, this translates to in excess of 12 kg/DTm. On the order of 200 *ppm* was noted as a reasonable value for many dewatered sediments. For $TS_{\%}$ of 10, this translates to 2 kg/DTm. Aggregate washing operations routinely dewater sediments that are essentially all minus 75 μm particles that are essentially non-plastic. Dosage rates on the order of 10 *ppm* were said to be typical. For $TS_{\%}$ of 10, this translates to 0.1 kg/DT_m.

The physical form and quantity of polymer needed dictate shipment, packaging, and on site storage (Hunter et al. 2006). Dry polymers are routinely delivered in small bags ≈ 25 kg, tay bags of 550 to 900 kg, re-useable stainless bins ≈ 900 kg, and in bulk silo systems ≈ 18,200 kg. Liquid polymers are routinely delivered in drums ≈ 200 L, tote bins ≈ 950 L, or in bulk ≈ 19,000 L.

Many variables influence the selection of equipment and chemical treatment; Englis and Hunter (2008) provide an excellent summary in terms of general dewatering applications. Regardless of the application, an in-depth understanding of the required performance standards must be present to select appropriate chemicals (i.e. polymers) and processes. Variables of interest to the current project that must be considered are:

- Production capacity will govern the size of the equipment.
- Limited access to a clean water source may eliminate some types of equipment that require large fresh water quantities. The *2008 Geotextile Tubes Workshop* of Howard et al. (2009) noted a clean water supply to be a potential concern in disaster response.
- Equipment may be necessary to screen the material and limit the particle size entering the dewatering equipment.
- The large volume of chemical additives required will likely require automated chemical make down equipment.
- Specialized metering equipment that can measure changes in slurry concentration and flow rate and correspondingly adjust properties will likely be needed.

Participants of Howard et al. (2009) indicated availability of sufficient containerized systems could limit the magnitude of response. Additionally, small polymer inventories could be a potential concern. Damage to the Gulf Coast could disrupt raw material supplies to the production locations, which could also prevent rapid manufacture of additional polymers. Stockpiled polymers might be required for this application; large quantities of polymers are often not manufactured until they are ordered.

2.3 Dewatering Techniques

Dewatering is a technique used in a variety of applications that crosses into many disciplines. Selection of appropriate dewatering technology must be based on equipment performance capabilities, sediment characteristics, chemical treatment required for optimal dewatering, and project objectives. Examples of materials that are routinely dewatered are dredged sediments, contaminated materials, municipal waste, sludge, industrial waste, and tailings.

Existing dewatering solutions include settling ponds, thickeners, cyclones, clarifiers, drying beds, landfills, presses (e.g. belt, plate, screw) centrifuges, heat, pyrolysis, geotextile tubes, and electroosmosis. Electroosmosis is using direct current to induce water movement. Electrical charge is theorized to cause flow due to drag forces for water near boundaries (e.g. soil) that would not otherwise flow. Englis and Hunter (2008) provided a relative comparison of many available dewatering techniques and qualitative comparisons of each

(Table 2.2). The authors also provided information to assist the end user in selection of appropriate dewatering technology.

Dewatering can be enhanced through the application of direct pressure and electricity. Gingerich et al. (1999) showed that aerobic sludge final cake total solids were approximately 50% after 20 minutes of 60 volts of direct current electricity and 51.7 kPa applied pressure.

Table 2.2. Comparison of Sediment Dewatering Devices of Englis and Hunter (2008)

Method	Belt Filter Press	Plate & Filter Press	Screw Press	Centrifuge	Geotextile Tube
Cake Solids	Med-High	High	Med-High	Med-High	High
Solids Capture	Med-High	High	Med	High	High
Solids Loading	Medium	Med-High	Low-Med	Med-High	High
Chemical Dose	Medium	Low	High	Med-High	Low
Overall Footprint	Sm-Med	Large	Med	Med	Large
Operation	Continuous	Batch	Continuous	Continuous	Continuous
Operation Ease	Easy-Mod	Mod-Diff	Mod	Diff	Easy
Noise Levels	Low-Med	Med	Low-Med	High	Low
Vapors/Fumes	High	Low-Med	Med	Med-High	Low
Capital Cost	Med	Med-High	Med-High	High	Med
Power Cost	Med	Med	Med-High	High	Low
Labor Cost	Low	Low-Med	Low	Low-Med	Med-High
Maintenance Cost	Med	Med-High	Med-High	High	Low
Overall Cost	Med	Med-High	Med-High	High	Low-Med

Note: Sm = Small; Med = Medium; Mod = Moderate; Diff = Difficult.

A centrifugal system with planetary rotation chambers capable of continuous dewatering without filters was investigated by Mohri et al. (2000). A prototype system (mild steel was the primary material) was fabricated with outer dimensions that would fit into a cube with 1.5 m sides, a total weight of 1,200 kg, and a dewatering capacity of 0.5 m^3/hr. The authors indicated that at the time of their work a full scale device with ten times the dewatering capacity could be fabricated for $80,000.

Mohri et al. (2000) tested four samples with the prototype device: 1) three samples of granite and/or silica composition containing 20 to 40% fines; and 2) one sample of Kaolin clay containing near 100% fines. The samples tested had initial water contents in excess of 250% and were all dewatered to below 50% moisture. The sample with near 100% fines posed the most difficulty in dewatering with centrifugal forces. Its moisture content was 48%, while the other samples were 27% or less. Centrifugal force was shown more significant than operation time.

2.3.1 Geotextile Tube Dewatering

Geotextile tubes used for dewatering are the focus of this section; marine and shoreline geotextile tubes are not considered. Properties of geotextiles used to fabricate geotextile tubes are also discussed. Geotextile tubes were developed in the 1980's. They are often used to dispose of high water content materials. *Tencate*™ company literature stated that between 1991 and 2008 there were over 2,000 dewatering projects that used *Geotube*®

units. According to Fowler et al. (2007) thousands of geotextile encapsulations (bags, tubes, and containers) have been filled with various materials in numerous countries for multiple purposes.

Geotextile tubes first confine the slurry, then excess water flows from the slurry, and thereafter long term consolidation occurs. Removal of excess water is of interest to this work. Acceptable percent solids levels can take two to three weeks for conventional applications. A typical application completely fills the tube, allows dewatering, cuts the tube, and hauls away the contents. A benefit of using geotextile tubes in many applications is they are passive and do not require continuous or extensive personnel resources, maintenance, or equipment.

Geotextile tubes have been filled with dredged slurries using cutter suction pipeline dredges for a considerable period. References date back to the early 1990's (e.g. Fowler and Sprague 1993). Geotextile tubes have been routinely used in conjunction with cutter head dredges (e.g. pumping 10% solid slurry at 11,000 Lpm with a 150 mm diameter pump).

Geotube® units have been modified for use on barges; e.g. ConEdison project in New York City discussed in *2008 Geotextile Tubes Workshop* report of Howard et al. (2009). Dredged slurry was improved from 2.5 to 58% solids in 7 days using 9.1 m circumference *Geotube*® units (G 2007-02 2007). Dewatering contaminated materials is also a proven *Geotube*® application. For example, G 2006-02 (2006) discusses dewatering 575,000 m^3 of river sediments using 22,800 linear meters of 24.39 m circumference geotextile tubes. Solids content increases of 30 to 40% are routine (e.g. ash lagoon waste dewatered from 23 to 60% solids in 30 days). See G 2007-02a (2007) for an example. Coal sludge has been dewatered to approximately 60% solids.

GT 500 is the predominant de-watering fabric of *Tencate*™. A significant amount of research was expended to develop the properties of the polypropylene material (i.e. tube capacity and dewatering rates). Polyester geotextiles are hydrophilic (have affinity for water) and can thus remove moisture via wicking. On the other hand, polypropylene geotextiles do not wick away moisture. In the early stages of dewatering, these behaviors are believed to be negligible.

Filtration behaviors have been investigated (e.g. Moo-Young and Tucker 2002). Filtration primarily views retention, permeability, and clogging as the parameters of interest. During the beginning of filtration the water and some fine particles flow out at high rates due to high geotextile permeability. Moo-Young et al. (2002) performed pressure filtration testing on four woven geotextiles to study soil retention and permeability. Two geotextiles were polypropylene and the other two were polyester. The permittivity ranged between 0.1 to 0.6 s^{-1}. Results showed the filter cake to be the major contributor to particle retention and decrease in permeability. Moo-Young et al. (2002) noted a much drier outer shell near the filter cake/geotextile interface.

Moo-Young and Tucker (2002) used vacuum testing to evaluate filtration and retention capacity of woven fabrics to increase solids retention while reducing excessive fines migration. Smaller particles tended to settle out at the top of the filter cake, leaving larger particles near the interface of the geotextile.

Clogging is the movement of soil particles into the voids of the geotextile, which reduces the hydraulic conductivity/permeability to near zero. Blinding occurs when soil particles build a layer often referred to as a filter cake that reduces geotextile permeability but does not stop water flow. The primary function of most geotextile tubes is to retain particles, not to deter clogging. Retention criteria often focus on larger sizes (e.g. D_{50} to D_{95} and O_{50} to O_{95}) of the soil and the geotextile, and have existed for some time (e.g. Calhoun 1972). In a similar manner, permeability criteria are numerous and have also existed for conventional applications for some time (e.g. Christopher and Holtz 1985). Gaffney et al. (1999) contends that within the *AOS* range of common geotextiles that soil particle size and *AOS* have very little to do with successful retention of material within a geotextile tube.

Moisture contents of 250%, 500%, and 1,200% were tested in conjunction with woven geotextiles with masses ranging from 200 to 900 g/m^2 for a variety of materials by Moo-Young and Tucker (2002). Particle retention was typically found to be greater than 90%. A USCS classified *CL* soil was tested at initial moisture contents of 250 and 500% to evaluate the gradient within the filter cake during vacuum filtration. The filter cake moisture content was found, in general, to range from: 53 to 58% at the top, 40 to 45% in the middle, and 27 to 32% at the bottom near the geotextile. Similar trends were mentioned for other soils, but were not reported by the authors.

Among other materials, a harbor sediment representative of hydraulic dredge sediment (LL of 48, PL of 30, 72% fines, and 9.6% organics) was tested by Moo-Young et al. (2002) at two initial water contents (142% and 326%). Two filtration pressures were used; 34.5 kPa and 69 kPa. Gaffney and Moo-Young (2000) reported filter cake formation to occur at 34.5 kPa and that this was representative of field conditions when filling a tube, whereas they used 69 kPa to replicate longer periods of time.

Moo-Young et al. (2002) referred to dewatering efficiency as change in percent solids divided by initial percent solids, reported values between 28 to 31% for the 142% initial moisture content, and reported values between 118 to 142% for the 326% initial moisture content. Likewise the dewatering rate (defined as slope of percent solids v/s time curve) was reported between 0.0043 to 0.0048 min^{-1} and 0.0161 to 0.0174 min^{-1} for the 142% and 326% moisture contents, respectively.

Gaffney et al. (1999) tested dredged material from New York Harbor containing 85% silt and 12% clay by placing it in a column and allowing drainage through a geotextile. Eight types of geotextiles were investigated. The result was a higher percent solids close to the geotextile with a progressive increase with distance. Woven polypropylene was the most efficient material evaluated in conjunction with the New York Harbor material (*AOS* of 40 and ψ of 0.3 s^{-1}).

In absence of evaporation, Gaffney et al. (1999) showed the moisture at 1.3(dia_{ca}) from the geotextile/soil interface would be essentially constant. The test device used by Gaffney et al. (1999) had an inner diameter of 101.6 mm, a 12.7 mm wall thickness, and was 584.2 mm tall. Diameter of contact area (dia_{ca}) was defined as the inner diameter of the Plexiglas tube. No polymers were incorporated in the testing for the paper. Gaffney et al. (1999) noted that other researchers also observed a dryer outer layer with high clay contents (i.e. on the order of 80%). Gaffney et al. (1999) also provided illustration of decreasing permeability leading to blinding, which resulted in a logarithmic increase in the moisture content as the distance from the geotextile/soil interface increases. This relationship is shown in Eq. 2.2.

$$\frac{D_{\text{int}}}{dia_{ca}} = 2.14943 \ln\left(\frac{W_{dist}}{W_{init}}\right) + 1.3019 \quad (R^2 = 0.91) \tag{2.2}$$

Where,

D_{int} = distance from geotextile/soil interface (mm)
dia_{ca} = diameter of contact area (mm)
W_{dist} = water content at D_{int}
W_{int} = initial water content of slurry

Filtration equations for a geotextile tube and a filter cake are often similar to Ohm's law for resistances in series. The equations do not typically incorporate Darcy's law. Gaffney et al. (1999) did not find the *AOS* to be significant compared to soil/geotextile permeability. Rules of thumb mentioned in the paper and used by others were soils with less than 50% fines required an *AOS* in excess of a No. 30 sieve, and soil with more than 50% fines required an *AOS* in excess of a No. 50 sieve.

As polymer treated fines enter the geotextile tube, agglomerated particles must be forming to prevent individual particles from migrating to the inner walls of the geotextile tube and blinding the material (i.e. forming a filter cake). If small enough, these individual particles could also exit the geotextile. A common and necessary practice is to include a sample valve between chemical addition port and the geotextile tube port that allows visual inspection of the conditioned soils; improper behavior can subsequently be addressed by adjusting dosage rates (Englis and Hunter 2008). Personnel may agitate the outer surface of the tube to discourage blinding and maximize dewatering rates. This can be performed with coarse brooms, walking on the tubes, or any other method of disturbing the tube that will break surface tension and facilitate drainage. Hand held mechanical vibrators have been used to dislodge the filter cake inside a *Geotube*® unit to expedite dewatering.

Fowler et al. (2007) reported on a case study where the hanging bag test was used as part of an experimental program and it did not show a significant dewatering time difference between lower and higher percent solids slurries. Additionally, a soil filter developed within the bags and caused the suspended solids (*SS*) to stabilize. A woven polypropylene geosynthetic (*GT 500*) was the outer layer of the hanging bag and the inner layer was a non-woven polypropylene fabric.

Fowler et al. (2007) also utilized full scale geotextile tubes in the experimental program. The geotextile tube was filled to a height of 1.5 m with an 8% solids material using a pressure of 207 Pa that was calculated using *GeoCoPS*. Consolidation of 90% occurred in the geotextile tube in approximately 26 days while it took on the order of 5 days in the hanging geotextile bags.

Fowler and Sprague (1993) reported results from two field case studies of interest to the current work. At Destin Harbor, FL it was observed: 1) geotextile tube design depends on discharge pressure, soil unit weight, and grain sizes; 2) higher tube pressures result in higher profiles; and 3) final tube heights were between 1.3 to 1.6 m. At Gaillard Island, AL it was observed: 1) greater pressures produce higher profiles; and 2) final tube heights ranged between 1.6 and 2.0 m.

Gaffney et al. (1999) provided some evidence that smaller circumference tubes were able to dewater to a greater percent solids than larger tubes. Small circumference tubes are also believed to dewater material more rapidly than larger circumference tubes. According to Fowler et al. (2007) geotextile tubes can increase the percent solids to approximately 25% relatively quickly. Key advantages for geotextile tubes in the current application are they have no moving parts and require no power in and of themselves. A noticeable disadvantage of geotextile tubes for the current application are their relatively large footprint. Geotextile tubes can be filled, consolidated, and re-filled. This is not necessarily a recommended practice, but for short term use such as dewatering this could be feasible.

2.3.2 Clarifiers

The *Clearwater Industries Model 2000 Portable Water Clarifier* is an example of equipment that would be suitable for the needs of a disaster. It is a totally self contained unit that contains a dry polymer feed system, clarification components, and a slurry pump capable of moving typical materials 240 m. The inlet capacity is 7,500 Lpm and the maximum slurry outlet capacity is 20% solids by volume (32 to 40% solids by weight for the materials under investigation in this research). The unit can be operational three hours after arrival on site, and requires 460 volt 3-phase power at 75 kW and a clean water source for polymer dosing. The dimensions of the equipment are 12.2 m by 3.4 m by 4.1 m tall. The empty weight is 18,000 kg and the operational weight is 52,000 kg. Additional information on the equipment can be found in IDR (2008).

There are a family of cyclone products (e.g. recovery, gravity, desliming) that could also be used for dewatering in the context of this project. Investigation of the full array of equipment that could potentially be used as is or modified for the needs of dewatering soil in a disaster area was beyond the scope of this project. The intent was to determine if products capable of performing in a disaster response were available; the portable water clarifier demonstrated such feasibility. How efficient or effective this type of approach might be has been left to other portions of this report.

2.4 Laboratory Sedimentation and Dewatering Testing

Dewatering and settling column test methods that were performed in the experimental program of this research have not been discussed in this section since they are described at length in Chapter 3. *Tencate*™ uses a *Geotube*® Rapid Dewatering Test (*RDT*) that is conceptually similar to the gravity flow drainage test used in this experimental program. Notable differences are *GT 500* is used instead of open weave belt cloth and the test duration is up to five minutes. A dewatering cone test also exists that, in principle, achieves similar goals as the aforementioned methods.

Sedimentation is separation of suspended particles and is widely used in water treatment operations. The settling velocity of solid particles is a key parameter that is used for a variety of functions including sizing of tanks and determination of production capacities. Chow et al. (1972) indicated satisfactory results could be obtained using a 150 mm diameter cylinder that was 3 m tall.

The USACE developed a sedimentation test some two decades ago where a 203 mm diameter Plexiglas tube was incorporated that had a practical depth limit of 183 cm. This device was described by several USACE reports during the period (USACE 1983, USACE 1987, and Palermo and Thackston 1988). Confined material disposal was of primary interest in the documents. The column was capable of introducing air from the bottom of the tube to keep the slurry mixed during column filling and capable of re-circulating slurry from the bottom of the column to the top. Polymer treated solutions were not considered when the air system was developed since the test was not intended for use with polymers. To charge the cylinder, dredged slurry was mixed in a tank adjacent to the column and pumped into the settling column. The sedimentation test for design of a dredge disposal area was typically conducted for 15 days. Depending on the reference, the first sample is to be taken at 1 to 2 hours after commencement. Recent internal USACE documents that are being considered for incorporation have similar requirements.

Flocculation of particles themselves is of note in USACE (1983). It was stated that a 203 mm diameter column was used to design a containment area for solids retention based on principles of flocculent or zone settling since they govern non-polymerized treated sedimentation in containment areas. According to Palermo and Thackston (1988), solids concentration in excess of 100 g/L may be characterized by zone settling, less than 100 g/L is typically characterized by flocculent settling. Wall effects were noted to affect zone settling velocities and that small diameter column tests are not acceptable for determination of zone settling velocities in that they do not accurately reflect field behavior. USACE (1987) states that a 1 L graduated cylinder should never be used for zone settling testing on sediment slurries representing disposal activities. Gravity settling test times such as for conventional disposal activities were noted to take 8 to 48 hours for a typical test. Note the testing described does not include chemical (e.g. polymer) conditioning.

In USACE (1983) a separate reference was given for chemical conditioning. USACE (1987) uses an example where chemical conditioning of 10 *ppm* was used for a containment area. The document also described a jar test where chemical conditioning was incorporated if inadequate suspended solids were removed during the 203 diameter sedimentation test described in the previous paragraph. Freshwater and high clay contents were noted to be a combination where there was often a need for chemical conditioning. According to USACE (1983) salinity greater than 3 ppt enhances flocculation of dredged material particles, which would lessen the need for chemical conditioning.

The jar test is conducted on 2g/L suspensions of sediment, which is intended to represent the effluent of a disposal facility. A low polymer dosage was listed as 10 *ppm* for the jar test in USACE (1987) for a 2 g/L concentration. Concentrations of 1 to 30 g/L are prepared and tested in the jar test to examine ranges of field conditions. The jar test is performed in a beaker of 1 to 2 L volume. The 2g/L suspension is dosed with polymer, mixed, and allowed to settle for 10 min. Turbidity and suspended solids are conducted on material from a water sample a moderate distance into the sample but not from the settled portion of the sample. Chemically treated material settles at a rate on the order of 0.13 cm/sec according to USACE (1987).

Shin and Oh (2003) performed settling velocity testing of a silty clay material (*ML* to *OL* with 82% fines, *LL* of 38, and *PI* of 6) pumped into a geotextile tube according to *USACE EM 1110-2-5027*. At a moisture content of 233% the settling velocity was 0.01 to 0.02 cm/sec. This settling rate is noticeably lower than the value from USACE (1987) found in the previous paragraph where chemical treatment was used.

2.5 Effect of Polymers on Portland Cement

Portland cement is modified with latex dispersions in some construction applications; modification of cement based materials with polymers has occurred for decades. The motivation of the polymer modification is to improve properties such as cohesion, adhesion, and flexural strength (Plank and Gretz 2008). Additionally, cationic and anionic polyelectrolyte effects on cement have been studied (Plank and Sachsenhauser 2009; Silva and Monteiro 2006).

Silva and Monteiro (2006) studied one water soluble polymer and one latex polymer and their effects on the early hydration of C_3A and C_3S. A soft X-ray transmission microscope (XM-1) was used. Images showed the water soluble polymer delayed hydration and promoted formation of inner products as opposed to outer products while slightly changing C_3A hydration. The latex polymer acted as a nucleation agent. The study focused on the first few minutes to the first few hours of the hydration process.

2.6 Summary of Literature and Practice Review

Dewatering soil from 10 to 30 $TS_{\%}$ for immediate re-use in a disaster environment appears feasible, though based on literature and practice review it may not be practical. Polymers are a crucial component of the dewatering needs of this project. A Gulf Coast hurricane could disrupt polymer supply lines and limit the availability of polymer during the critical period of disaster recovery. Limited clean water could be problematic, but the specific details cannot be anticipated for a disaster. The required dosage rate of the polymer is anticipated to be crucial to the practicality of the research; this is investigated later in this report.

Pre-fabricated equipment packages that can be inserted directly into a response plan were identified in the *Ciba Corporation* enclosed liquid polymer make down system and the *Clearwater Industries* portable clarifier and polymer make down units. A limited supply of enclosed polymer systems and the operational weight of the portable clarifier are potential problems with a practical use in a disaster area.

The filter cake inside a geotextile tube is believed to be the major contributor to permeability decrease and is drier than the remaining material inside a geotextile tube; this has been observed with high clay contents and no polymer treatment was mentioned in the research documents that presented these results. Polymer treated sediment is believed to be able to reduce (or in some cases prevent) individual particles from migrating to the inner walls and forming a filter cake. Agitation (e.g. mechanical vibration) can be effective in discouraging filter cake formation. Small circumference geotextile tubes are believed to dewater soil more rapidly and to higher percent solids.

CHAPTER 3 – EXPERIMENTAL PROGRAM

3.1 General Information

The experimental program was focused on rapidly de-watering soil for subsequent use as a stabilized emergency construction material. Cementitiously stabilized testing was performed in this report to investigate the effect of polymers on shear strength. Significantly more cementitiously stabilized research related to stabilization can be found in *SERRI Report 70015-006* where polymers were not incorporated. To develop the experimental program for this research, existing approaches were complimented by technique modifications and non-standard test methods to develop an experimental program suitable to meet project objectives. The materials and test methods employed are provided in the remainder of this chapter.

3.2 Materials Tested

3.2.1 Soils Tested

Three soils were used for dewatering experiments, which were also used in *SERRI Report 70015-006*. Therein, a suite of geotechnical tests were performed on the materials and a description of the test methods was provided. In summary, *Soil 1* was classified as *CL* to *CH*, *Soil 2* was classified as *MH* to *CH* to *OH*, and *Soil 3* was classified as *CH* to *OH*. Soil test methods related specifically to dewatering are described in Section 3.3, while other test data has been omitted from this document.

3.2.2 Geotextiles and Fabrics Tested

The *Geotube®* Dewatering Test (*GDT*) incorporated *GT 500* fabric. An open weave belt cloth was used for gravity flow drainage testing. The material was one that the Ciba laboratory has used for a period of time. Experience has shown that for small volumes the open weave cloth is more appropriate. Flow of water through the open weave belt cloth is from the smooth side to the rough side. The material is designed for one directional flow and could clog if flow occurred in the other direction. Typical properties of the open weave belt cloth are provided in Table 3.1, while properties of the *GT 500* fabric were provided in *SERRI Report 70015-003* and are obtainable from other sources.

Table 3.1. Properties of Open Weave Belt Cloth

Property	Result
Composition	Polyethylene (PET)
Type	Industrial Fabrics IFC 6093
Air Permeability	10.2 m^3/min
Weight	1 kg/m^2
Weave	Satin 25 by 9 threads/cm

3.2.3 Polymers Tested

Both dry and liquid grade polymer dewatering products were tested since the best delivery methods in the disaster environment are unknown. Polymers tested are shown in Table 3.2. Note that sizeable polymer companies have well over 100 products to choose from and that the polymers were selected based on significant experience with soil dewatering. All polymers tested were water soluble.

Table 3.2. *Ciba Corporation* Dewatering Polymers Tested

Product Name	Product ID	Physical Form	Active	Charge Density[1]	Rel. Mol. Wt.
KRYSALIS®	FC2043	Dry-Powder Grade	100%	*VL(+)*	High
KRYSALIS®	FC2077	Dry-Powder Grade	100%	*L(+)*	High
KRYSALIS®	FC2106D	Liquid Dispersion	50%	*L(+)*	High
KRYSALIS®	FA2308	Dry-Powder Grade	100%	*H(-)*	Very High

1: L = Low, VL = Very Low, H = High, Cationic = (+), Anionic = (-)

3.2.4 Dispersants Tested

A pilot investigation was conducted to select dispersants for use with small column testing. Five products were tested having varying water solubility: Tamol® 681, 850, 901, 963, and 2001. Tamol® 681 is an ammonium salt of a hydrophobic copolymer dispersant. Tamol® 850 is a highly carboxyl-functional dispersant and scale inhibitor. Tamol® 901 is a low foaming poly acid pigment dispersant. Tamol® 963 is a non-foaming poly acid dispersant. Tamol® 2001 is a high-performance hydrophobic copolymer dispersant.

Testing was performed in 100 mL graduated cylinders with *Soil 2*. The Tamol® products were combined with FC2043 polymer so that the dosage of FC2043 was always twice that of the Tamol® product; e.g. if 6 kg/DT_m of FC2043 was used then 3 kg/DT_m of the Tamol® product of interest was used. Testing was also performed with only FC2043 for a reference. Tamol® 850 and Tamol® 963 were selected for use with small column testing.

3.2.5 Portland Cements Tested

Three portland cements were tested. Two of the cements were from Holcim's Artesia, MS facility. The first (*A T III*) is a commercially available *Type III* product, while the second (*SC1*) is a specialty grind that is a modification of *A T III*. The third cement (*Th T III*) was a commercially available *Type III* product from Holcim's Theodore, AL facility. Details of these cements are provided in *SERRI Report 70015-006*.

3.3 Preparation of Materials

3.3.1 Preparation of Diluted Polymer Solution

The dry polymer used during testing was made down into a liquid form; see Figure 3.1. During the makedown process, 100% activity was assumed (94 to 96% is realistic of actual conditions), and a 0.5% concentration by weight was used (i.e. 0.5 g of polymer in 100 ml of liquid) unless specifically stated otherwise. The liquid used to makedown the polymer was comprised of 3% acetone and 97% deionized water by volume. Most of the polymer was made down in 19L plastic pails to accommodate the large volumes of testing performed; smaller volumes were made down in smaller plastic containers in the same manner. The dry polymer was first added to the bottom of the container, and acetone was slowly added around the sides of the container as shown in Figures 3.1a and 3.1b. The container was gently agitated after the addition of acetone in order to lubricate the polymer. After polymer lubrication, the deionized water was added to the container and stirred then shaken vigorously for 5 minutes as seen in Figures 3.1c and 3.1d. The container was also shaken for a few seconds every 15 minutes during the first hour after mixing to ensure that the polymer remained sufficiently mixed. The polymer solution was typically made down 10 L at a time, but smaller quantities were made down as needed using the same proportions of dry polymer and liquid described above. The maximum shelf life allowed for polymer solution was 14 days from the time the polymer was first mixed. Dry polymers and polymer solutions were stored at room temperature.

(a) Addition of Dry Polymer

(b) Addition of Acetone

(c) Stirring of Polymer Solution

(d) Shaking of Polymer Solution

Figure 3.1. Make Down of Polymer Solution

3.3.2 Preparation of Soil Slurries

Soil slurries were prepared for this research in two fashions. The first was to add a quantity of soil to a quantity of water, mix them together, and then measure the specific gravity (or density) of the slurry by placing a sample in a known volume container and recording its mass. The consistency of slurries prepared in this fashion are reported with a specific gravity of slurry value (SG_{slurry}). The entrapped air was not measured which would prevent calculations from producing more than an estimate of other properties using the G_s term common in geotechnical engineering. An unknown air volume for a given SG_{slurry} only allows determination of water to within a few ml, which is sufficiently accurate for the testing and analysis of this research. The second method of preparing slurries was to batch quantities in a manner to achieve $TS_{\%}$ of 10, which were indicated by this value. This was performed in the same manner as in *SERRI Report 70015-006*.

3.3.3 Preparation of Polymer Dosed Soil Slurries

Dosage rates are typically expressed as mass of active polymer (kg or lb) per mass of dry solids (metric ton or English ton) being dewatered. In this report two terms were used: 1) kg/DT_m (kilograms of active polymer per metric ton of dry solids to be dewatered); and 2) lb/DT (pounds of active polymer per English ton of dry solids to be dewatered). The first step in dosing was to select the dosage rate in kg/DT_m. Next, the amount of polymer in kg/DT_m was converted to *ppm* according to Eq. 2.1. Once the *ppm* was determined for the dosage rate of interest (kg/DT_m), the volume of polymer solution was determined by using parts-per notation knowing the volume of slurry to be treated. For example, treating 1000 ml of slurry at 83 *ppm* with a 0.5% polymer solution would require 16.6 ml of polymer solution (1 mL of 0.5% neat polymer added to 1000 mL of soil slurry is equivalent to 5 *ppm*). The appropriate amount of diluted polymer solution was placed into a prepared soil slurry and agitated to mix them and allow the polymer to attach to the soil particles. The agitation technique varied with test method and has been presented with each individual test method. The amount of water added with the polymer dilution was accounted for in analysis as appropriate.

3.3.4 Preparation of Stabilized Soil Slurries

The material prepared in Section 3.3.3 was dewatered using the *GDT Standard Method 2* described in Section 3.4.5.1. Testing resulted in differing final total solids contents. Effluent water was captured during the *GDT* test that was used to increase the dewatered soil to $TS_{\%}$ of 30 for cases where the soil had dewatered below this level. For cases where $TS_{\%}$ was greater than 30 at the conclusion of *GDT* testing the material was allowed to dry at room temperature to achieve the desired solids content for stabilization with portland cement and subsequent testing for shear strength. The same moisture condition was desired of all testing to maintain consistency.

3.4 Test Methods

3.4.1 Measurement of Soil Properties

Soil properties specific to the dewatering portion of the research are presented in this section. As discussed elsewhere, other properties have been measured on these soils. Where applicable, brief discussion of the testing beyond this report has been presented.

3.4.1.1 Particle Size Analysis

Particle size analysis was conducted using mechanical sieves and a *Horiba CAPA 910* instrument. Particle sizes larger than 75 µm were determined using the mechanical sieves, while particle sizes smaller than 75 µm were determined using the *Horiba CAPA 910* which uses a laser scattering technique. The laser detects particles in an aqueous phase and was performed on samples of slurry on the order of 1 L that contained on the order of 100 g of solids. The *Horiba CAPA 910* looks for spherical particles and ignores objects that are not near spherical in shape. It is primarily used to measure polymer particle sizes. Polymer particles are often on the order of 1 µm and are largely round.

The test conducted was not according to a standard method and is by volume rather than the customary particle size analysis by mass used by geotechnical engineers. Comparison of particle sizes using a hydrometer and the *Horiba CAPA 910* should be performed with caution and should consider the items mentioned previously. Approximate laser particle size analysis such as with the *Horiba CAPA 910* are common in water treatment since they utilize on hand equipment and provide a quick and repeatable method to characterize the soil in absence of additional equipment.

3.4.1.2 Dry Slurry Solids

Total solids were calculated using Eq. 1.5 for all portions of the experimental program. Figure 3.2 shows the relationship between total solids ($TS_{\%}$) and moisture content ($w_{\%}$). Determination of dry solids for the testing described in Sections 3.4.2 and 3.4.3 of this experimental program consisted of taking a known quantity of the mixed slurry and drying it in a fan assisted oven at 110 C for two hours and recording the residual weight. The method is Part 2540B of the *American Public Health Association* (Clesceri et al. 1998). Dry solids were determined by drying a sample to constant mass in the remainder of the research as this is the standard approach in geotechnical engineering.

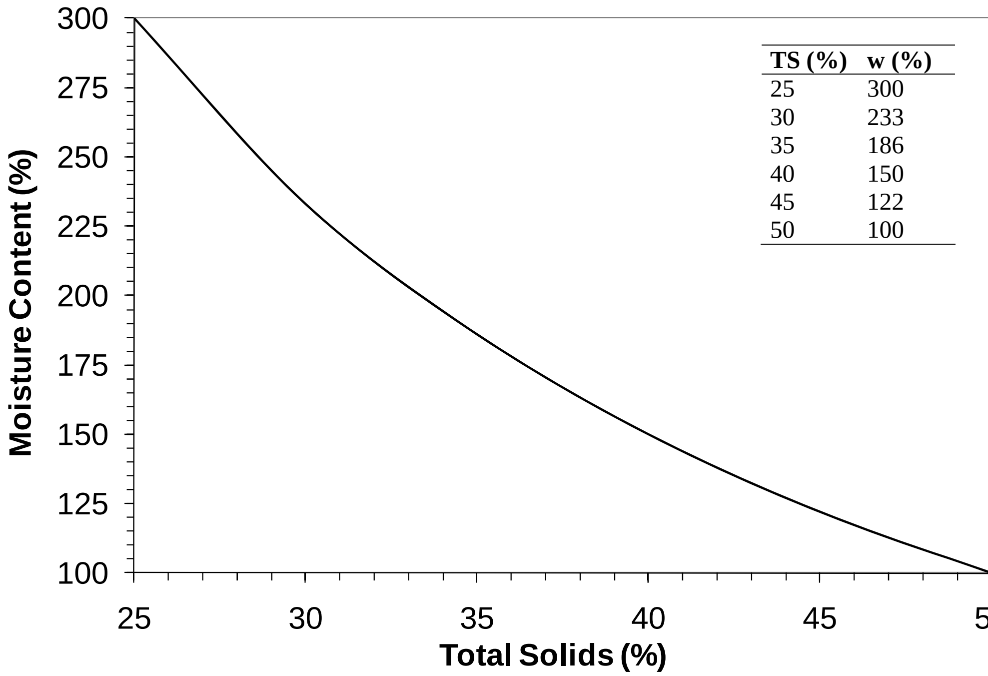


Figure 3.2. Relationship Between Moisture Content and Total Solids

3.4.1.3 Organics/Volatiles

Organics/volatiles testing conducted specifically for this report was performed in the following manner. The soils were tested at 550 C according to method 2540E of the *American Public Health Association* (Clesceri et al. 1998) and samples were prepared according to method 2540B from the same organization with minor modifications. Test method 2540B calls for temperatures of 103 to 105 C, but the samples for this research were prepared at 110 C. Test method 2540B of Clesceri et al. (1998) notes prolonged drying could be needed in some conditions. Additionally, Clesceri et al. (1998) states that total dried solids may not represent the weight of actual dissolved and suspended solids. Furthermore, residues dried at the temperatures of this method may retain crystallized and mechanically occluded water. Test method 2540C provides an alternate sample preparation method where samples are heated to 180 C, which is stated to remove all water. Finally, method 2540B can be ceased when a weight change of less than 4% is observed.

Organics/volatiles testing performed in *SERRI Report 70015-006* was in accordance with ASTM D 2974, which incorporates a 750 C temperature and samples that have no moisture. This is in contrast to method 2540B where moisture could remain. Note that regardless of the moisture when the specimens were placed in the muffle furnace, the sample exiting the furnace would have no moisture.

3.4.2 Gravity Flow Drainage Testing

Dry soil was first mixed into a slurry (typically several liters), and then 200 ml portions (i.e. aliquots) of soil slurry were taken that contained no polymer modification. The slurry was categorized by SG_{slurry}. A 0.2% active polymer solution was then added to the 200 ml aliquot using a syringe. The aliquot and polymer solution were mixed by applying shear via transfer between two beakers; ten transfers were used for all testing. After the tenth transfer the soil slurry was deemed conditioned.

The conditioned soil slurry was poured into a 76 mm inner diameter drainage tube resting in a Buchner Funnel that contained an open weave belt cloth (Table 3.1). The soil slurry was allowed to freely drain through the cloth for 15 seconds while the filtrate passing through the cloth was collected. At the end of the 15 second period, the volume of filtrate was recorded.

3.4.2.1 Filtrate Volumes

During preparation and conditioning of samples, materials added were recorded and accounted for in the following manner. The 200 ml aliquot was taken from the mixed soil slurry of known density (SG_{slurry}). Within this 200 ml volume would be soil solids, water, and air. The amount of air was not measured, which prevented an exact determination of the amount of water. A reasonable estimate for the density of the slurries tested in this report would be 180 to 190 ml of the volume was water.

During testing, two volumes were measured: 1) volume of 0.2% active polymer solution, which for calculations was assumed to all be water (V_P); and 2) volume of filtrate captured at the conclusion of 15 seconds of drainage (V_F). The net filtrate volume (V_{FN}) is the difference in the terms ($V_F - V_P$), which represents the amount of water in the original sample that was removed.

3.4.2.2 Turbidity

The residual turbidity of the filtered water samples was determined using a *Hach 2100P Turbidimeter*. The filtrate collected from the gravity flow drainage testing was stirred, sampled, and inserted into the turbidimeter cell. The test was conducted in accordance with method 2130B of Clesceri et al. (1998). The result of testing is recorded in Nephelometric Turbidity Units (NTU's). Turbidity is an indicator of the correct polymer and dosage combination. As a point of reference, turbidity of drinking water is on the order of 5 or less. The lower the NTU, the cleaner the filtrate water.

3.4.3 Piston Dewatering

The polymer and dosage combination producing the best results from gravity flow drainage testing was used to perform piston dewatering tests. These tests were performed in a cylinder on the order of 75 mm diameter where the pressure was increased on the sample up to 275 kPa over a 30 minute press cycle. *GT 500* fabric was placed at the bottom of the sample to simulate geotextile tube dewatering. At the conclusion of testing, the percent solids were calculated to evaluate dewatering efficiency.

3.4.4 Settling Column Testing

The primary variable investigated via settling column testing was the dosage rate of polymer; one polymer (FC2043) was used for all testing. A secondary variable was the effect of dispersants on dewatering, which was investigated with small column testing. The dosage rate was varied to provide sufficient data for evaluation of the effect of dosage rate when dewatering soil slurry. Small settling column variables included soil type (three soils) and water type (three waters) used in the mixing of soil slurry. Large settling column testing included one soil and one water type. Details of each test method are provided as follows.

3.4.4.1 Small Settling Column Testing

Two test protocols were used for small settling column testing. Protocol 1 was used for the majority of the testing and is the protocol being discussed unless specifically stated otherwise. Protocols 1 and 2 are described in the two subsequent paragraphs, respectively.

The column used for Protocol 1 small scale testing was a 1000 mL graduated cylinder with a height of 47 cm and a 6 cm diameter. A number 13 rubber stopper was used to seal the column opening. Prior to the addition of a given volume of polymer solution, the soil slurry was agitated using a drill with mixer bit, and then 1000 mL of slurry was extracted and poured into the column as seen in Figures 3.3a and 3.3b, respectively. The soil slurry contained $TS_{\%}$ of 10 and was originally mixed a minimum of 24 hours prior to dewatering. The polymer solution was added and the rubber stopper was secured onto the column opening as shown in Figure 3.3c. To effectively mix the slurry and polymer solution, the column was inverted 10 times, as in Figure 3.3d, and placed on a level surface. A stopwatch was started at the conclusion of Figure 3.3d, and the water and soil solids began to separate. The top of the flocculated soil/water interface, hereafter referred to as the soil level, was measured every 10 seconds for the next 120 seconds. The soil level was also measured at 180, 240, and 300 seconds. The water level at the beginning of the test was determined at the end of 300 seconds and was taken to be the height of all material in the column. For analysis, the change in soil level was determined by subtracting the water level at the beginning of the test from the soil level reading at each time interval. Figure 3.3e displays the column at the completion of testing. After all soil levels were read and recorded, all free water was removed so the remaining soil could be tested for $TS_{\%}$ as seen in Figure 3.3f.

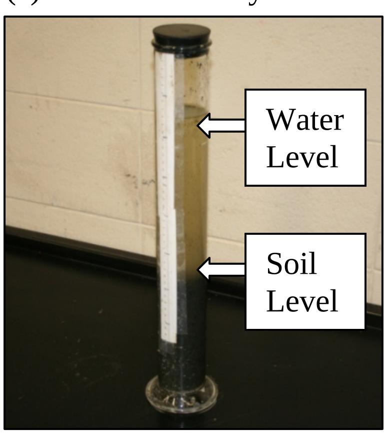
The column used for Protocol 2 small scale testing was a 2000 mL graduated cylinder with a height of 52 cm and a diameter of 8.25 cm. Parafilm was used to seal the opening during agitation. Prior to addition of polymer the soil slurry was agitated with an electric mixer, and once mixed 950 mL of soil slurry was poured into the graduated cylinder. The soil slurry contained $TS_{\%}$ of 10 and was mixed the day before use. The polymer solution was mixed the day before use, and when dispersants were used they were added just before placement into the soil slurry. Once the polymer was added the cylinder was thoroughly shaken, placed upright, and settlement recorded every ten seconds for the first 120 seconds and then on 60 second intervals until 300 seconds.

(a) Agitation of Soil Slurry

(b) Slurry Prior to Addition of Polymer

(c) Addition of Polymer

(d) Mixing of Soil Slurry and Polymer



(e) Fully Settled Column

(f) Dewatered Slurry Removal

Figure 3.3. Addition and Mixing of Soil Slurry and Polymer Solution

3.4.4.2 Large Settling Column Testing

The Plexiglas column used for large scale dewatering testing was 152 cm tall with a 19 cm inner diameter with graduations along the side (Figure 3.4a). A glass plate was secured to the bottom of the column and attached to a small table to form the testing apparatus. Two 1.9 cm holes, one in the bottom and one in the side of the column, were drilled and threaded caps were placed to allow for removal of material. The inside of the column was sprayed with water before the first test to provide a consistent surface since the column was cleaned with water after each test. The soil slurry had $TS_{\%}$ of 10 which was mixed a minimum of 24 hours before testing.

The amount of material needed for each test was divided into three buckets (3.32 kg of dry solids were used for each test). The soil slurry in each bucket was agitated with a drill and mixer bit attachment prior to the addition of the appropriate amount of polymer solution. Once the polymer solution was added, agitation of the slurry continued for a few seconds, and then the entire contents of the bucket were poured into the column as seen in Figure 3.4b. After each of the remaining buckets of material were agitated and dosed with polymer, they were quickly added to the column without interruption between buckets. The pouring of material into the column produced enough mixing action to prevent settling of soil solids until all material was added to the column. The method of introduction and level of agitation prior to initiating the test is a potential area for improvement.

Once all material had been poured from the last bucket into the column, a stopwatch was started while the column was in the initial condition shown in Figure 3.4c. The top of the flocculated soil/water interface, hereafter referred to as the soil level, was measured every 10 seconds for the next 300 seconds. The soil level was measured every 60 seconds after 300 seconds until 1200 seconds (20 minutes) was reached. The water level at the beginning of the test was determined after 1200 seconds and was taken to be the height of all material in the column. For analysis, the change in soil level was determined by subtracting the water level at the beginning of the test from the soil level reading at each time interval. Figure 3.4d shows the column at the conclusion of testing and shows that the soil water interface can be easily seen. After all soil level readings had been taken, the free water was drained out of the side of the column by removing one of the 1.9 cm plugs, leaving only the dewatered soil. The dewatered soil was removed by taking out the other 1.9 cm plug which was in the bottom of the column. All dewatered soil was retrieved and thoroughly mixed so a sample could be taken to measure $TS_{\%}$ at the end of dewatering.

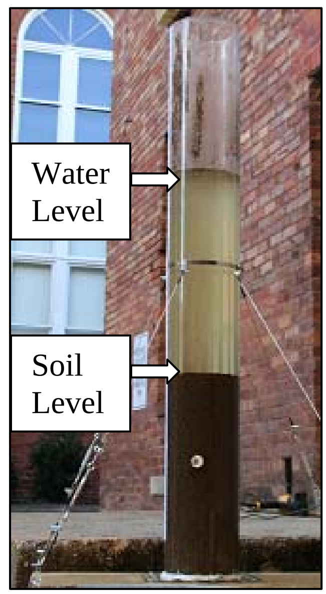
3.4.4.3 Material Removal Settling Column Testing

The large settling column was filled with soil slurry or water and the material subsequently drained from the bottom of the column. The change in height with time was recorded. Three replicates were performed for water and three more replicates were performed for *Soil 3* with 5.5 kg/DT_m dosing and $TS_{\%}$ of 30. The testing was intended to evaluate the ability to remove dewatered soil from a geotextile tube with a given amount of pressure from the material in the tube.

(a) Large Settling Column

(b) Addition of Dosed Slurry to Column

(c) Dosed Slurry at Beginning of Testing



(d) Fully Settled Column

Figure 3.4. Large Settling Column Test Method

3.4.5 *Geotube*® Dewatering Test (*GDT*)

The *Geotube*® Dewatering Test (*GDT*) was used in the standard fashion during initial portions of the research. The test was also modified to investigate parameters associated with removal of material during dewatering. The test methods for each of these conditions are described in the remainder of this section.

3.4.5.1 *GDT* Standard Method

A small-scale geotextile tube is used to conduct the experiment, which has dimensions of approximately 530 mm by 530 mm and holds approximately 28,000 cm^3 of material. *GT 500* geotextile is used along with conventional seams. The small-scale tube is often referred to as a *pillow*. Two versions of the standard test were performed during this research. The first was performed at the *Ciba Corporation* laboratory in Suffolk, VA, which has been referred to as *GDT Standard Method 1*.

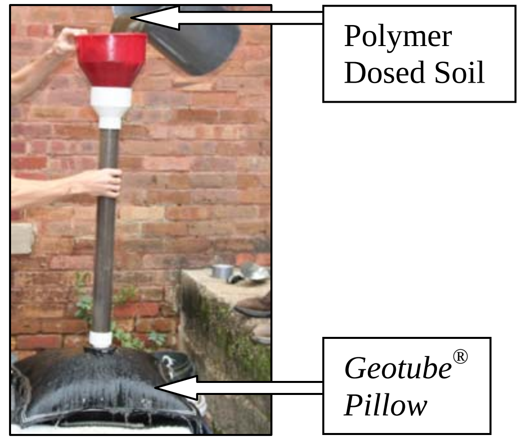
To perform *GDT Standard Method 1,* a 38 liter aliquot of the slurry was taken for testing. The aliquot was subsequently divided into five equal parts and mixed with the polymer that had been diluted to a 0.5% active solution by transferring the slurry and polymer between two pails (up to four transfers). The conditioned soil was then introduced into the *pillow* via the top funnel. Two hours of drainage occurred after the last of the slurry had been introduced into the *pillow*, and at the end of testing the *pillow* was cut open and material removed for testing. Testing consisted of $TS_{\%}$ measurement and yield stress measurement. Yield stress was measured using a *Brookfield YR-1 Rheometer*, which simulated passage through pumps at 20, 50, and 100 plunges. A V74 spindle was used at a rotational speed of 5 rpm.

To perform *GDT Standard Method 2*, the stand was leveled before testing, and the top funnel was secured to the *pillow*. The material to be dewatered had an initial $TS_{\%}$ of 10, and the slurry was mixed a minimum of 24 hours before testing. The amount of material needed for each test was divided into 8 buckets (11.36 kg of dry solids were used in each test).

The soil slurry in each bucket was agitated with a drill and mixer bit attachment prior to the addition of the appropriate amount of polymer solution as shown in Figure 3.5a. Once the polymer solution was added, agitation of the slurry continued for a few seconds, and then the entire contents of the bucket was poured through a funnel into the standpipe and *pillow* assembly as shown in Figure 3.5b. Note that the funnel, standpipe, and *pillow* were held slightly above the stand when the first bucket of material was added to allow the *pillow* to fill properly. After the first bucket of material was added, the standpipe and funnel were held upright, but the *pillow* was allowed to rest on the stand. The remaining buckets were then dosed and poured into the funnel. The amount of time between dosage and addition of the soil slurry to the *pillow* was minimized to eliminate the possibility of premature settling of soil solids.

Once all the material had been dosed and poured into the funnel timing commenced and the material was allowed to dewater for the required time. Once the required time was reached, the bag was cut open as shown in Figure 3.5c, and a total of 10 samples were taken to test for $TS_{\%}$. Four of the samples were taken from the top of the dewatered soil on each corner of the *pillow*, and 4 additional samples were taken approximately 2.5 cm from the bottom of the *pillow* on each corner below the locations shown in Figure 3.5d. The remaining two samples were larger samples, both taken from the middle of the dewatered soil. One sample was taken from the dewatered soil as seen in Figure 3.5e, and one sample was taken after the dewatered soil had been thoroughly mixed as seen in Figure 3.5f.

(a) Agitation and Dosage of Slurry



(b) Pouring of Dosed Slurry into *Pillow*

(c) Cutting of *Pillow* after Dewatering

(d) Corner Sampling of Soil

(e) Sampling of Soil Middle

(f) Sampling of Soil after Mixing

Figure 3.5. Geotube® Dewatering Test (GDT) Method

The time of drainage within the *GDT* test has not been established by *Tencate*™. Common evaluation times were noted by company representatives to be 2 hr, 24 hr, and 168 hr depending on the dewatering characteristics observed during testing and the goals of the project. No direct method to extrapolate to full scale exists, though the better the dewatering polymer is matched to the sediment the faster dewatering will occur. No data prior to 2 hr (120 min) was found with exception of the testing in this research. All testing in this research focused on rapid dewatering (120 min or less). Water effluent is often of interest in typical testing but was not considered in this report.

3.4.5.2 *GDT* Modified for Material Removal

The *GDT* dewatering test was modified by adding a 2.5 cm diameter fitting in the bottom of the *pillow* incorporating a threaded cap (Figure 3.6a). The material was prepared in the same manner as a standard test and was introduced into the *pillow*. At the end of the allotted time, the threaded cap was immediately removed to determine the extent the dewatered material would flow from the *pillow* (e.g. Figure 3.6b). The dewatering time was determined from standard *GDT* testing determined using the approach in Section 3.4.5.1.

(a) Port Installed in Bottom of Pillow

(b) Material Flowing from Geotextile Pillow

Figure 3.6. GDT Test Modified for Material Removal

3.4.6 Testing of Polymer Dewatered and Cementitious Stabilized Soils

Eight unconfined compression (*UC*) suites and one trial of slabs were tested that were dewatered using FC2043 polymer. Both the suites and the trial were tested according to Protocol 2 of *SERRI Report 70015-006*; curing occurred at room temperature in 100% humidity (*UC* specimens were submerged). All testing was performed on specimens produced at a moisture content ($w_{\%}$) of 233 ($TS_{\%}$ of 30) and total cementitious content of 15; this combination is denoted (15, 233) hereafter. The purpose of testing was to measure the undrained shear strength (s_u) as a function of temperature-time factor.

Six suites were *Soil 3* and were dewatered with 1.25 and 5.5 kg/DT$_m$ of polymer; three cements (*A T III*, *Th T III*, and *SC1*) were used for each polymer dosage rate. One suite was tested with *Soil 1* dewatered with 6 kg/DT$_m$ and stabilized with *Th T III*, and one suite was tested with *Soil 2* dewatered with 12 kg/DT$_m$ and stabilized with *Th T III*. *Soil 3* dewatered with 5.5 kg/DT$_m$ and stabilized with *Th T III* cement was tested via the trial protocol using hand held gages. Each soil was dewatered using the *Geotube*® *Dewatering Test* (*GDT*) using the optimum polymer dosage rate determined using gravity flow drainage testing, while *Soil 3* was also dewatered with the *GDT* using a 1.25 kg/DT$_m$ polymer dosage rate determined using settling column testing Protocol; 1. Five control suites and one control trial were tested without polymer for comparison to the polymer dewatered materials.

CHAPTER 4-TEST RESULTS

4.1 Material Property Test Results

Soil particle sizes and organic content are provided in the remainder of this section. Additionally, comparison is provided to applicable properties obtained using geotechnical engineering approaches. These test methods were described in *SERRI Report 70015-006*.

4.1.1 Particle Size Test Results

Figures 4.1 and 4.2 provide particle size information obtained from the laser technique. The majority of the particles by volume were distributed around 0.01 mm. The sizes of the different soils were not observed to be appreciably different using the laser technique. Table 4.1 compares the laser and hydrometer test results. The laser technique and the hydrometer provide noticeably different particle sizes in some cases. The comparison was very reasonable for *Soil 1*, but for *Soil 2* and *Soil 3* (organic soils) the results were noticeably different. The hydrometer data shown was from processed soil.

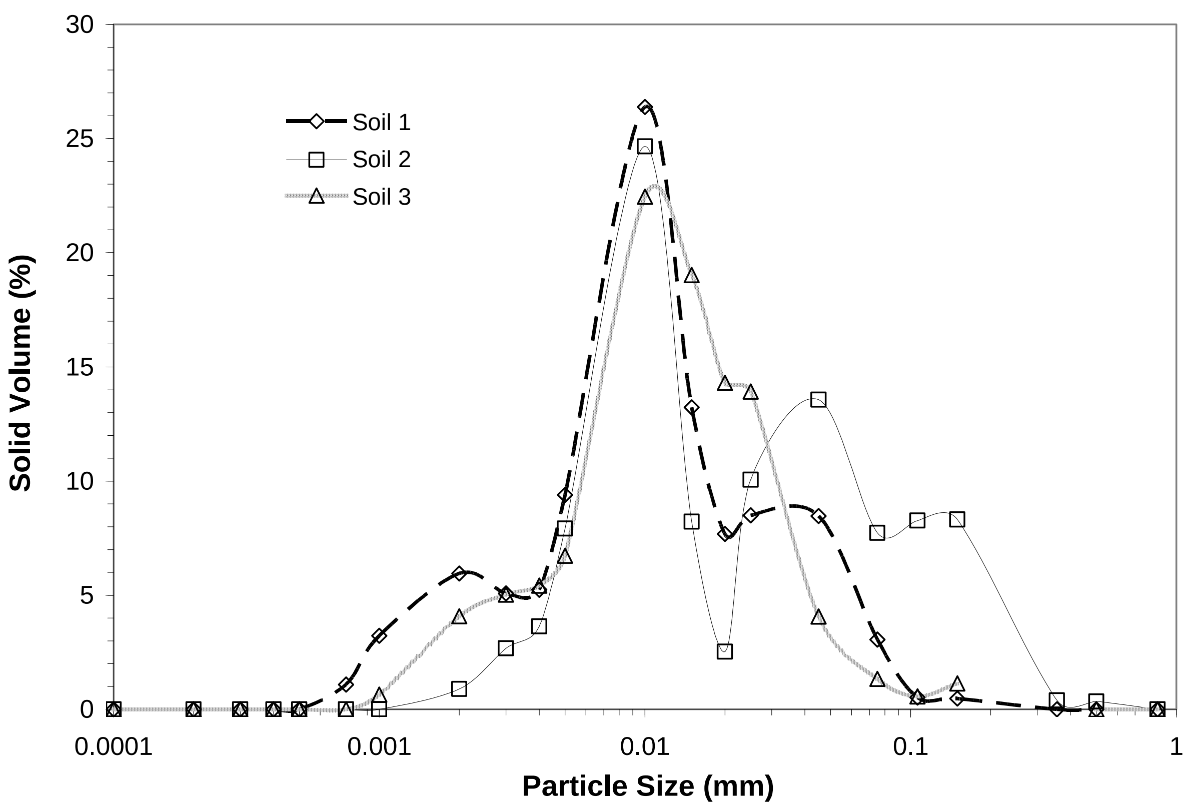


Figure 4.1. Solid Volume Versus Particle Size Using Laser Technique

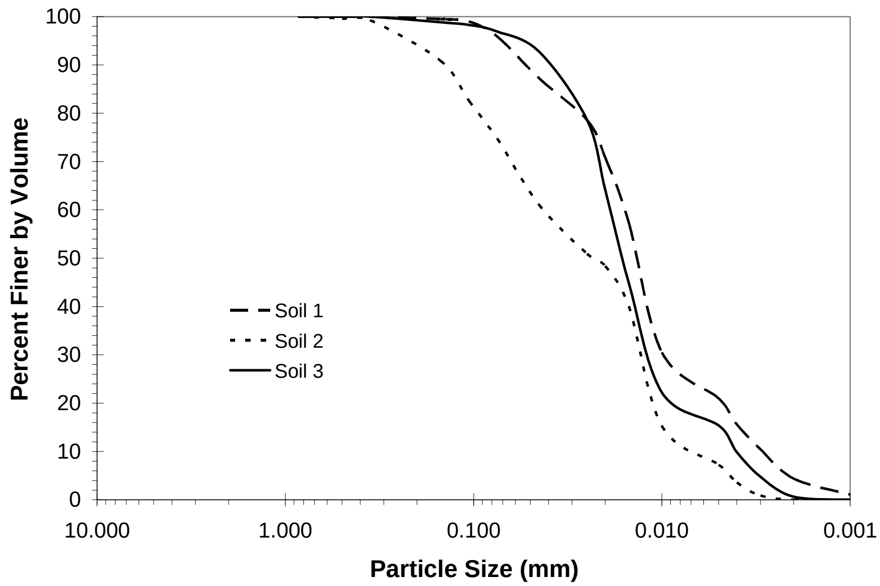


Figure 4.2. Cumulative Particle Size Analysis Using Laser Technique

Table 4.1. Comparison of Laser and Hydrometer Testing

	Laser (µm)			Hydrometer (µm)		
Soil	D_{10}	D_{50}	D_{90}	D_{10}	D_{50}	D_{90}
1	3	14	52	<1	5 to 13	50 to 90
2	4	23	105	<1	<1.5	15 to 90
3	7	17	38	<1	<1.8	18 to 72

4.1.2 Organics and Volatiles Test Results

Organics/volatiles test results can be seen in Table 4.2 alongside the corresponding test methods. Based on discussion in Chapter 3, the results of D 2974 would be expected to be less than or equal to those of 2540E when prepared according to 2540B. As seen in Table 4.2, this is the case for *Soil 1* and *Soil 3*. *Soil 2* had a noticeable difference in organic content, but additional organic testing of *Soil 2* provided in *SERRI Report 70015-006* showed significant point to point variations in organic content. Values were measured between 11.4

Table 4.2. Organics and Volatiles Test Results

Soil	Source	Test Method[1]	Organics/Volatiles (%)
1	New Orleans	2540E	9.4
		D 2974[2]	4.2
2	New Orleans	2540E	14.6
		D 2974[2]	24.2
3	Mobile	2540E	10.4
		D 2974[2]	10.6

1: D 2974 is an ASTM Method and 2540E is a Water and Wastewater Method.
2: Average of five tests on processed soil.

and 36.2, so it could easily be that the single measurement from method 2540E was a sample with lower organics. Note that precise distinction between inorganic and organic matter is not made with a loss on ignition test.

4.2 Gravity Flow Drainage Test Results

Gravity flow drainage experiments were conducted by *Ciba Corporation* in their Suffolk, VA laboratory. Table 4.3 summarizes slurry characteristics used in these experiments, and as seen they were constituted by the SG_{Slurry} approach described in Chapter 3. Soil processed according to *SERRI Report 70015-006* was used to produce the slurries.

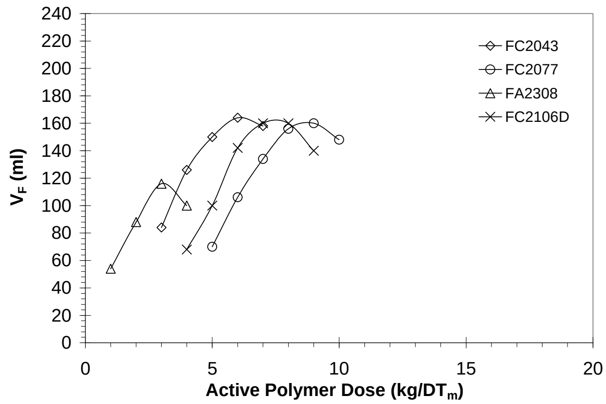
Table 4.3. Slurry Characteristics for Gravity Flow Drainage Experiments

Soil **Source**	1 New Orleans, LA	2 New Orleans, LA	3 Mobile, AL
Water	Freshwater	Freshwater	Freshwater
pH	7.5	7.5	7.9
Visual Description	Dark Brown	Dark Brown	Dark Grey
$TS_{\%}$	8.44	9.16	10.04
SG_{Slurry}	1.084	1.079	1.072
Surface Area (m^2/ml)	18,317	10,317	15,496

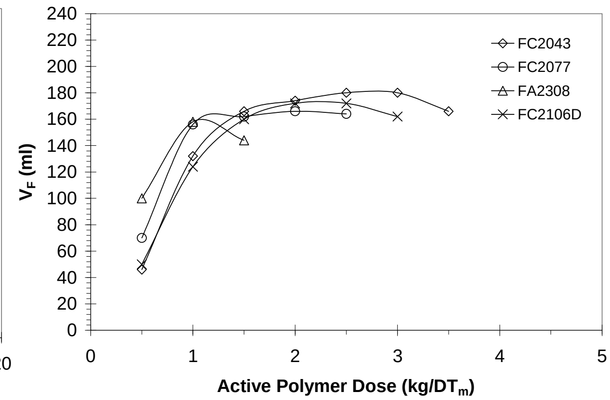
Figures 4.3 through 4.5 plot the results of gravity flow drainage testing, while the tabular results are provided in Tables 4.4 through 4.6. Figure 4.3 plots total filtrate volume (V_F) versus polymer dosage rate which includes fluid volume added with the polymer. Figure 4.4 plots net filtrate volume (V_{FN}) versus polymer dosage rate which has accounted for fluid volume added with introduction of polymer by removing it via calculation. Figure 4.5 provides turbidity data of the effluent filtrate water.

Table 4.7 summarizes the results of all testing and provides the optimal polymer selection in liquid and dry form based on gravity flow drainage testing. Table 4.8 provides the optimal dosage rates of the polymer found to be the optimal selection; FC2043. Dose requirements varied significantly between freshwater (rainwater) and saltwater (seawater). Freshwater slurries required significantly higher polymer doses than saltwater slurries. A possible reason could be the salt inhibiting the clay particles within the slurries from swelling, thus reducing surface area and polymer demand. Additionally, the charge the salt carries will affect the Zeta potential of the individual clay particles and help break down the double wall. These behaviors make flocculation easier. It can be seen from Figure 4.5 that the saltwater slurries produced lower turbidity filtrate. Saltwater slurries were more effectively dewatered than freshwater slurries.

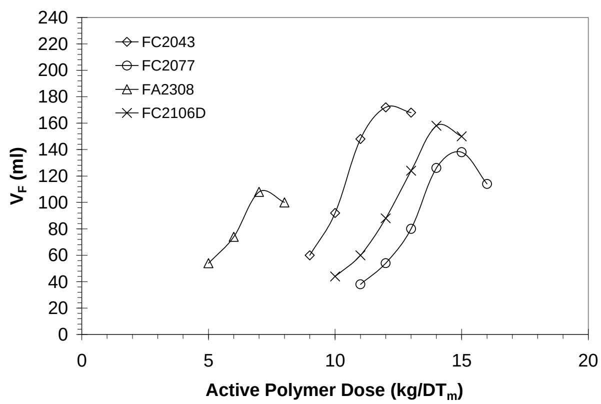
From Figures 4.4 and 4.5 it can be seen that dewatering in either freshwater or saltwater is not, in general, significantly affected at polymer dosages within $\pm$ 1 kg/DT_m of optimal. At lower polymer dosages, dewatering was noticeably less effective in the gravity flow drainage testing. The magnitude of polymer required to dewater these soils is noteworthy and is, in general, higher than the values from previous projects found in Table 2.1. The magnitude of polymer available in a disaster could pose difficulty in utilizing the optimal dewatering rates found from gravity flow drainage testing.



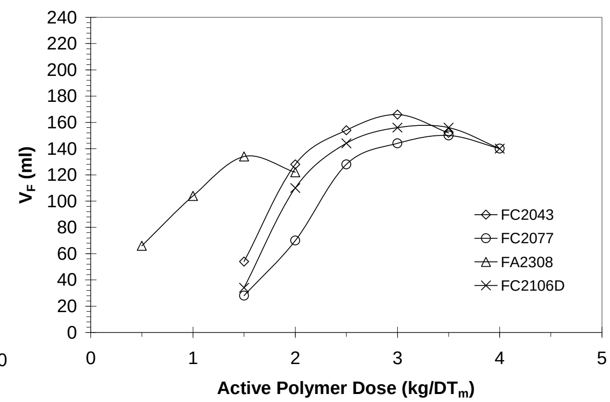
(a) Soil 1-Freshwater



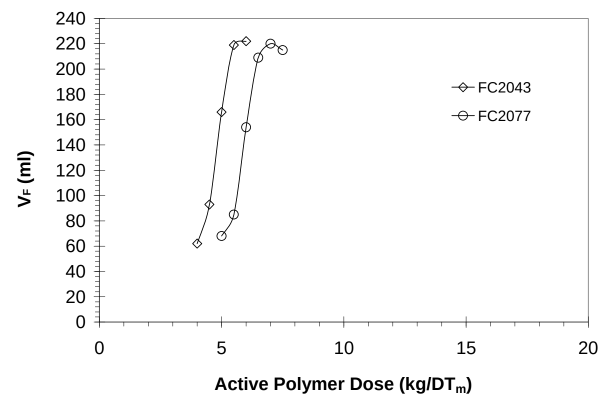
(b) Soil 1-Saltwater



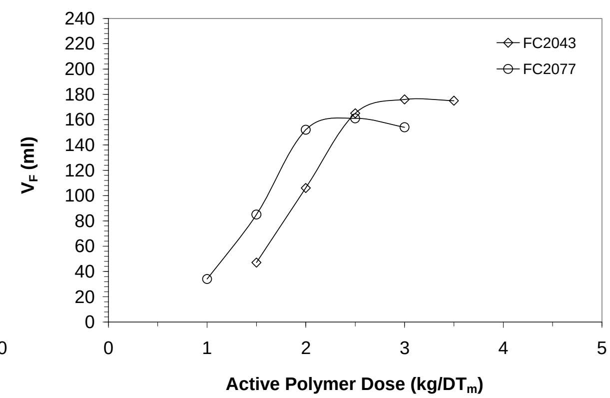
(c) Soil 2-Freshwater



(d) Soil 2-Saltwater

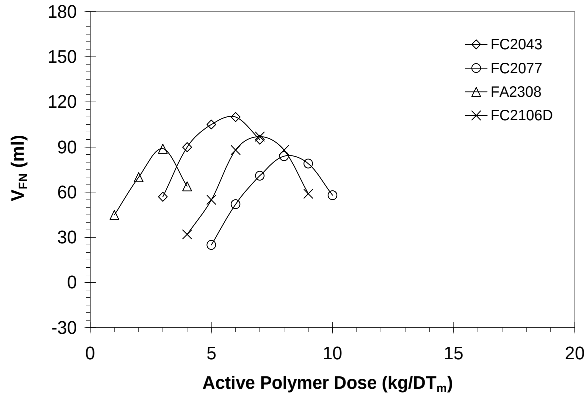


(e) Soil 3-Freshwater

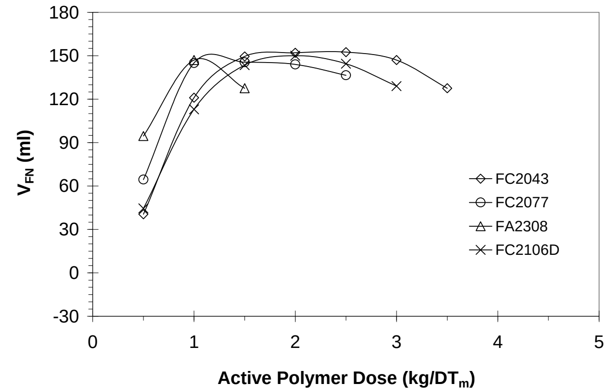


(f) Soil 3-Saltwater

Figure 4.3. Filtrate Volume (V_F) Versus Polymer Dosage Rate



(a) Soil 1-Freshwater



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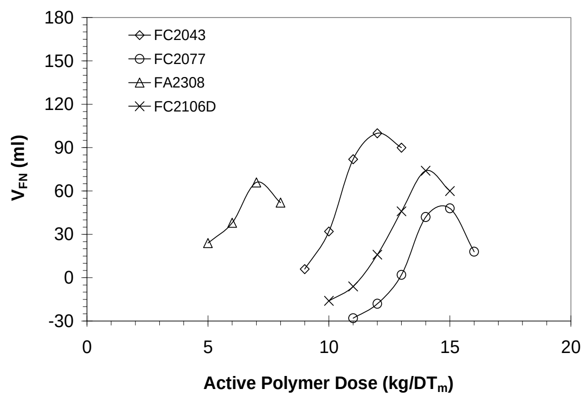
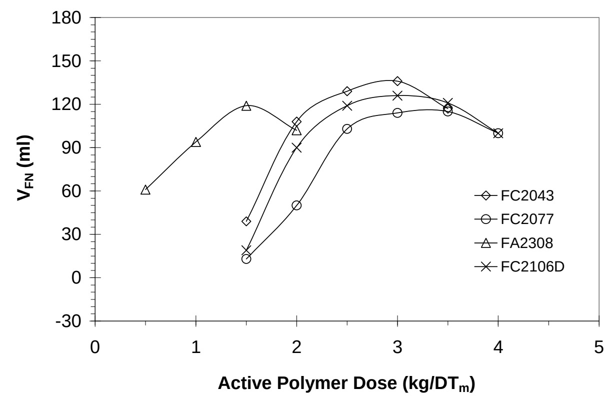
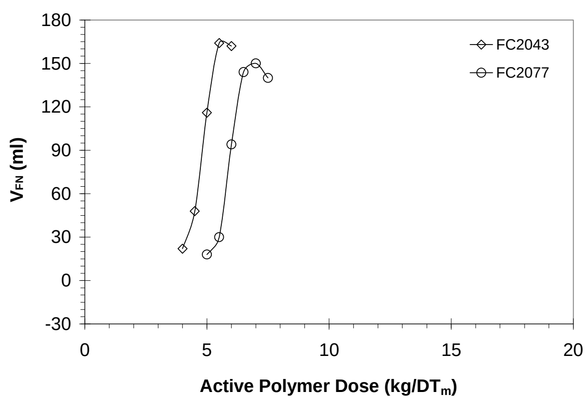


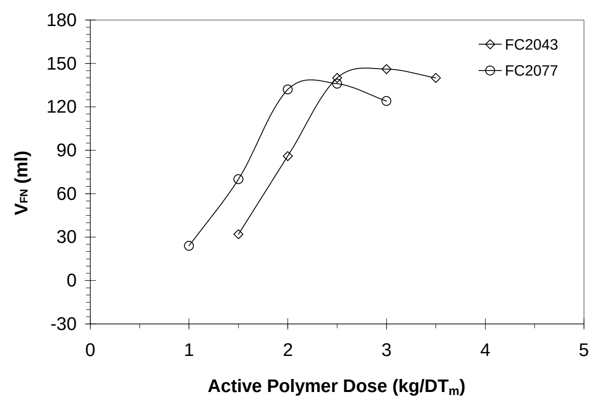
(c) Soil 2-Freshwater



(d) Soil 2-Saltwater

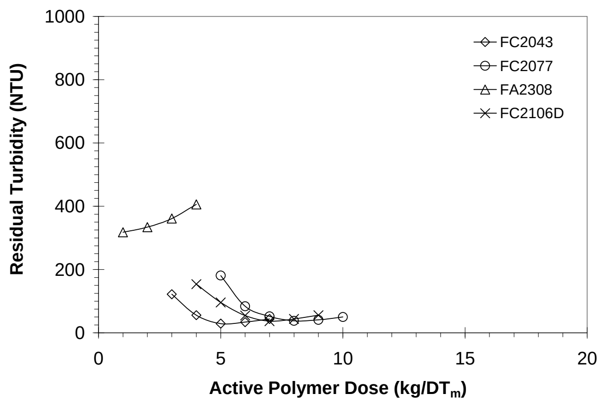


(e) Soil 3-Freshwater

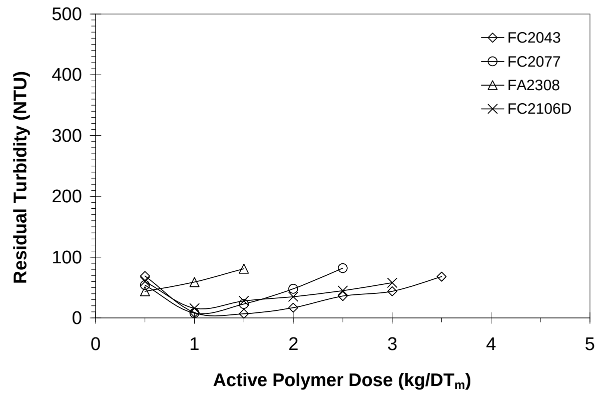


(f) Soil 3-Saltwater

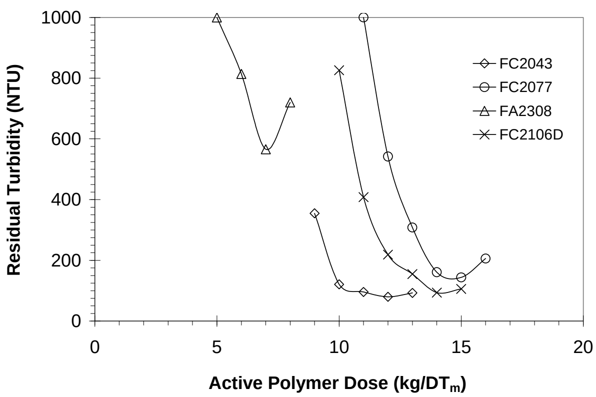
Figure 4.4. Net Filtrate Volume (V_{FN}) Versus Polymer Dosage Rate



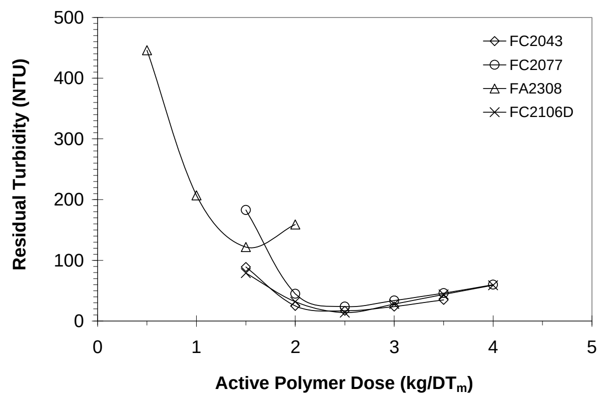
(a) Soil 1-Freshwater



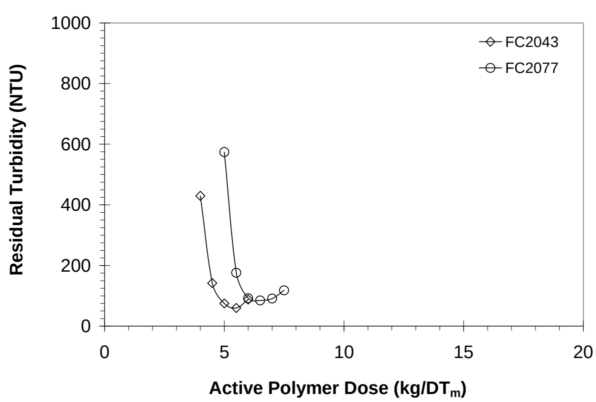
(b) Soil 1-Saltwater



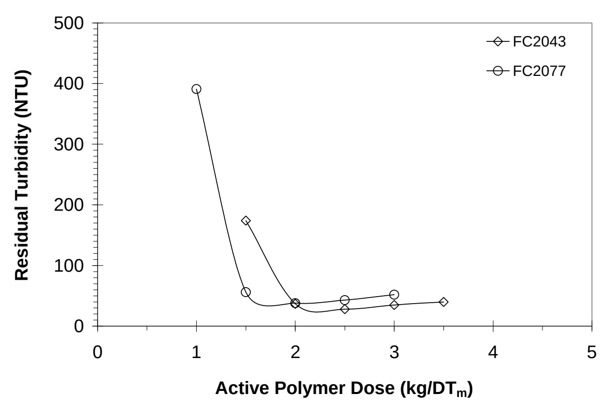
(c) Soil 2-Freshwater



(d) Soil 2-Saltwater



(e) Soil 3-Freshwater



(f) Soil 3-Saltwater

Figure 4.5. Residual Turbidity Versus Polymer Dosage Rate

Table 4.4. Gravity Flow Drainage and Turbidity Test Results for *Soil 1*

Water	Polymer	Active Dose (kg/DT_m)	V_P (ml)	V_F (ml)	V_{FN} (ml)	Turbidity (NTU)
Fresh	FC2043	3	27	84	57	122
		4	36	126	90	56
		5	45	150	105	29
		6	54	164	110	34
		7	63	158	95	44
	FC2077	5	45	70	25	181
		6	54	106	52	84
		7	63	134	71	52
		8	72	156	84	38
		9	81	160	79	41
		10	90	148	58	50
	FA2308	1	9	54	45	318
		2	18	88	70	334
		3	27	116	89	361
		4	36	100	64	406
	FC2106D	4	36	68	32	154
		5	45	100	55	96
		6	54	142	88	55
		7	63	160	97	37
		8	72	160	88	44
		9	81	140	59	56
Salt	FC2043	0.5	6	46	40	69
		1	11	132	121	9
		1.5	16	166	150	7
		2	22	174	152	17
		2.5	28	180	152	36
		3	33	180	147	44
		3.5	39	166	127	68
	FC2077	0.5	6	70	64	54
		1	11	156	145	8
		1.5	17	162	145	23
		2	22	166	144	48
		2.5	28	164	136	82
	FA2308	0.5	6	100	94	44
		1	11	158	147	59
		1.5	17	144	127	81
	FC2106D	0.5	6	50	44	60
		1	11	124	113	16
		1.5	17	160	143	28
		2	22	172	150	35
		2.5	28	172	144	45
		3	33	162	129	58

Table 4.5. Gravity Flow Drainage and Turbidity Test Results for *Soil 2*

Water	Polymer	Active Dose (kg/DT_m)	V_P (ml)	V_F (ml)	V_{FN} (ml)	Turbidity (NTU)
Fresh	FC2043	9	54	60	6	355
		10	60	92	32	121
		11	66	148	82	96
		12	72	172	100	80
		13	78	168	90	93
	FC2077	11	66	38	-28	1000
		12	72	54	-18	542
		13	78	80	2	308
		14	84	126	42	161
		15	90	138	48	144
		16	96	114	18	206
	FA2308	5	30	54	24	1000
		6	36	74	38	814
		7	42	108	66	566
		8	48	100	52	720
	FC2106D	10	60	44	-16	826
		11	66	60	-6	408
		12	72	88	16	219
		13	78	124	46	155
		14	84	158	74	94
		15	90	150	60	106
Salt	FC2043	1.5	15	54	39	89
		2	20	128	108	25
		2.5	25	154	129	17
		3	30	166	136	24
		3.5	35	152	117	35
	FC2077	1.5	15	28	13	183
		2	20	70	50	45
		2.5	25	128	103	24
		3	30	144	114	34
		3.5	35	150	115	46
		4	40	140	100	60
	FA2308	0.5	5	66	61	446
		1	10	104	94	207
		1.5	15	134	119	122
		2	20	122	102	159
	FC2106D	1.5	15	34	19	79
		2	20	110	90	32
		2.5	25	144	119	14
		3	30	156	126	28
		3.5	35	156	121	44
		4	40	140	100	59

Table 4.6. Gravity Flow Drainage and Turbidity Test Results for *Soil 3*

Water	Polymer	Active Dose (kg/DT_m)	V_P (ml)	V_F (ml)	V_{FN} (ml)	Turbidity (NTU)
Fresh	FC2043	4	40	62	22	430
		4.5	45	93	48	142
		5	50	166	116	75
		5.5	55	219	164	60
		6	60	222	162	88
	FC2077	5	50	68	18	574
		5.5	55	85	30	176
		6	60	154	94	92
		6.5	65	209	144	85
		7	70	220	150	91
		7.5	75	215	140	118
Salt	FC2043	1.5	15	47	32	174
		2	20	106	86	37
		2.5	25	165	140	28
		3	30	176	146	35
		3.5	35	175	140	40
	FC2077	1	10	34	24	391
		1.5	15	85	70	56
		2	20	152	132	38
		2.5	25	161	136	43
		3	30	154	124	52

Table 4.7. Optimal Products From Screening Tests

		Optimal Product		
Soil	**Source**	**Dry**	**Liquid**	**Overall**
1	New Orleans	FC2043	FC2016D	FC2043
2	New Orleans	FC2043	FC2016D	FC2043
3	Mobile	FC2043	----	FC2043

Table 4.8. Optimal FC2043 Dosage Rates From Gravity Flow Drainage Tests

		Optimal Dosage Rate (lb/DT)		Optimal Dosage Rate (kg/DT_m)	
Soil	**Source**	**Freshwater**	**Saltwater**	**Freshwater**	**Saltwater**
1	New Orleans	12	5	6	2.5
2	New Orleans	24	6	12	3
3	Mobile	11	5	5.5	2.5

4.3 Piston Dewatering Results

Table 4.9 provides results from piston dewatering experiments (slurries were those shown in Table 4.3). In conventional applications, $TS_{\%}$ from piston dewatering is believed to be one of the most significant performance indicators. For immediate dewatering applications, relative trends are of key interest. Cake solids were higher in saltwater than in freshwater, which compliments turbidity and dosage results that slurries of the soils tested are easier to manage in saltwater.

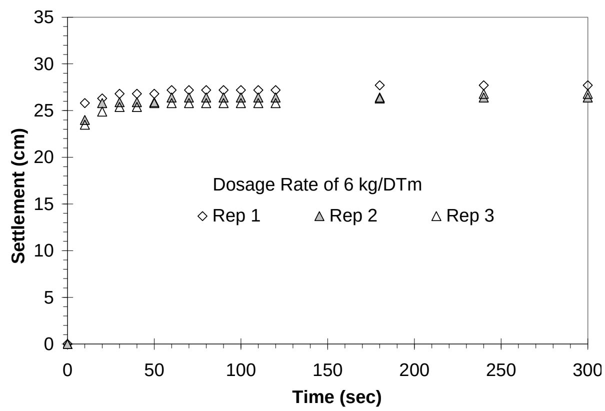
Table 4.9. Piston Dewatering Test Results

Slurry	Polymer	Active Dose (kg/DT_m)	Active Dose (lb/DT)	$TS_{\%}$ (%)
Soil 1/Freshwater	FC2043	5	10	48.3
		6	12	51.6
		7	14	50.4
Soil 1/Saltwater	FC2043	2	4	63.9
		2.5	5	67.5
		3	6	64.3
Soil 2/Freshwater	FC2043	11	22	41.3
		12	24	44.6
		13	26	44.6
Soil 2/Saltwater	FC2043	2.5	5	54.7
		3	6	58.3
		3.5	7	57.7
Soil 3/Freshwater	FC2043	5	10	43.8
		5.5	11	46.5
		6	12	45.0
Soil 3/Saltwater	FC2043	2	4	44.3
		2.5	5	51.4
		3	6	48.6
Soil 1/Freshwater	FC2016D	6	12	49.6
		7	14	52.4
		8	16	50.1
Soil 1/Saltwater	FC2016D	2	4	63.5
		2.5	5	66.8
		3	6	66.0
Soil 2/Freshwater	FC2016D	13	26	39.2
		14	28	42.2
		15	30	42.5
Soil 2/Saltwater	FC2016D	2.5	5	52.2
		3	6	55.6
		3.5	7	56.4

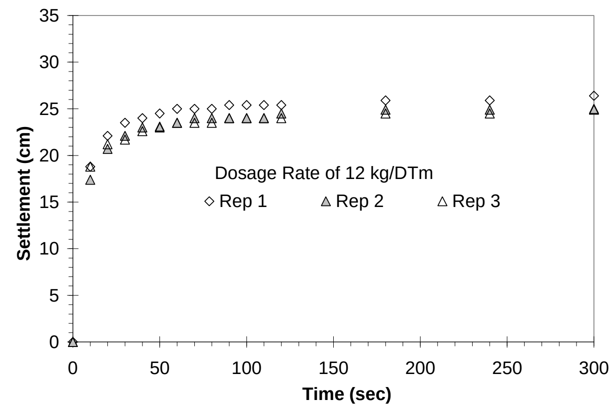
4.4 Settling Column Test Results

4.4.1 Small Column Test Results

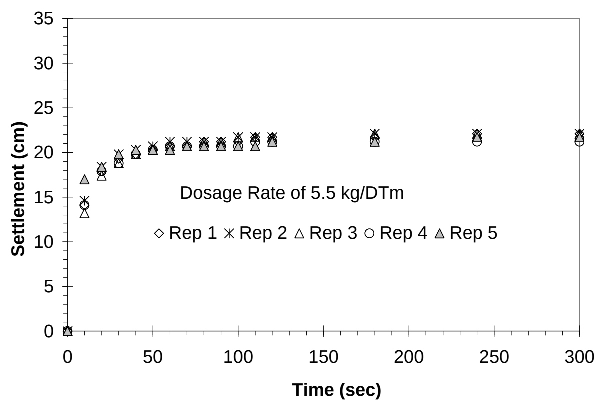
Thirty-seven small column tests were conducted using Protocol 1; twenty-five were conducted with *Soil 3* in freshwater, three with *Soil 3* in brackish water, three with *Soil 3* in saltwater, three with *Soil 1* in freshwater, and three with *Soil 2* in freshwater. Figure 4.6 provides settlement versus time test results. Figure 4.6e indicates three zones of settling velocity with time: 1) 0.50 to 0.65 kg/DT_m; 2) 0.75 to 2.0 kg/DT_m; and 3) 2.5 to 7.5 kg/DT_m. Within each category the trend of increased settling velocity with increased polymer is not always observed between any two dosage rates, but in general the trend is observed.



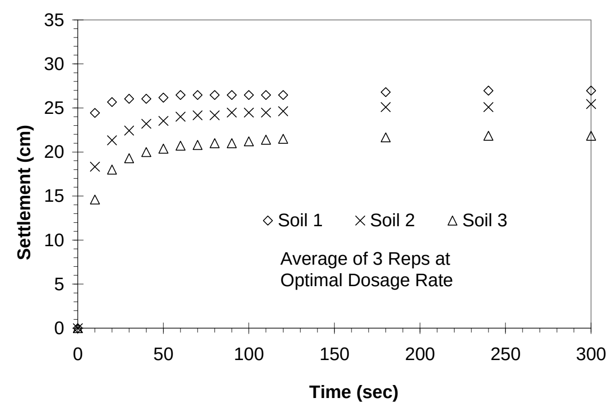
(a) Soil 1-Freshwater-Optimal



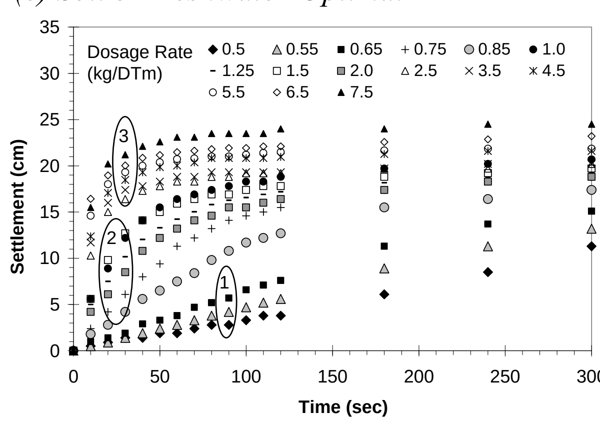
(b) Soil 2-Freshwater-Optimal



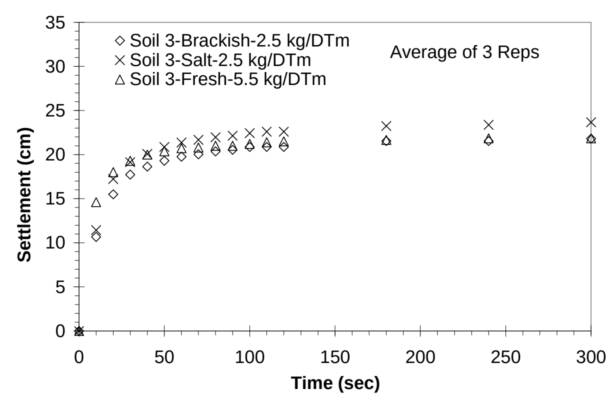
(c) Soil 3-Freshwater-Optimal



(d) All Soils-Freshwater-Optimal



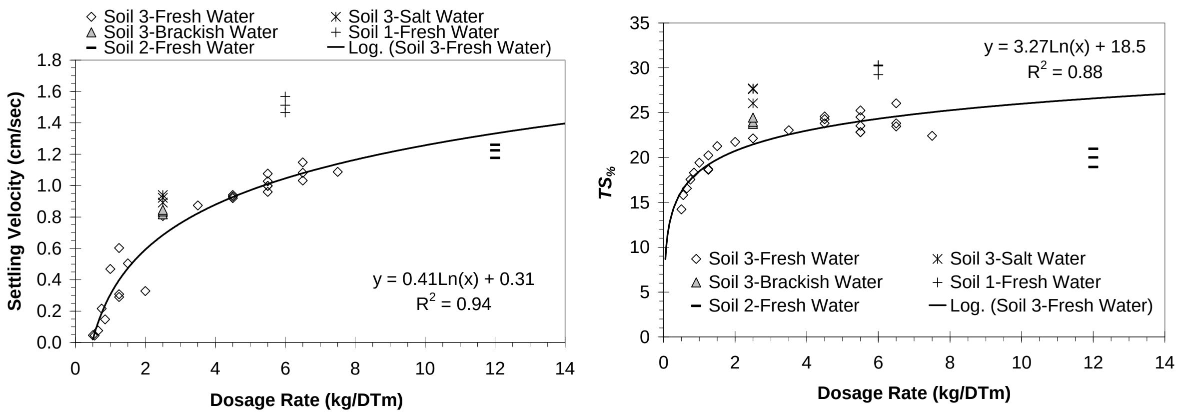
(e) Soil 3-Freshwater-Multiple Rates



(f) Soil 3-Varying Water

Figure 4.6. Protocol 1 Small Settling Column Test Results for Settling Versus Time

Figure 4.7a uses the plots from Figure 4.6 to calculate settling velocity (slope of settlement versus time curve) using data from the first 20 seconds of testing. It can be seen in Figure 4.6 that the curves become non-linear at or just after 20 seconds as particles come into contact with each other in the small column. *Soil 1* settling rates shown in Figure 4.7a were initially faster than shown (e.g. at 10 seconds). The curve had already started to break by the third measurement (20 seconds in Figure 4.6a) indicating settling velocities in small columns for materials that settle as well as *Soil 1* become questionable. It can be seen that there is a strong trend of settling velocity and polymer dosage rate for the specimens tested. Figure 4.7b plots $TS_{\%}$ versus polymer dosage rate at the conclusion of testing (300 sec or 5 min); a strong correlation was also observed. The mixing energy applied to the small column was consistent, though it cannot be quantified relative to field mixed material based on currently available data.



(a) Settling Velocity (20 Seconds) *(b) $TS_{\%}$*

Figure 4.7. Protocol 1 Small Settling Column Test Results for Settling Velocity and $TS_{\%}$

Using the Figure 4.7a trend line and calculating the dosage rate that achieved a 0.13 cm/sec settling rate resulted in a dosage rate of 0.65 kg/DT_m. Equipment dosage rate capacities were 0.65 to 1.30 kg/DT_m based on analysis provided in Chapter 5. Predicted settling velocities within 0.65 to 1.30 kg/DT_m dosage rates using small column data are 0.13 to 0.41 cm/sec for *Soil 3*. In *Soil 3*, salt water had a higher settling velocity and $TS_{\%}$ than brackish water which had a higher settling velocity and $TS_{\%}$ than fresh water. *Soil 1* was the easiest to dewater followed by *Soil 3* and then *Soil 2*. The lower the organic content the easier the soil was to dewater in absolute terms.

Figure 4.8 plots small column settling test results using *Soil 2* and Protocol 2. The dosage rate of FC2043 was 6 kg/DT_m and the dosage rate for both Tamol® dispersants was 3 kg/DT_m. The performance of FC2043 alone was at or better than the combined blends. No further testing of dispersants was performed.

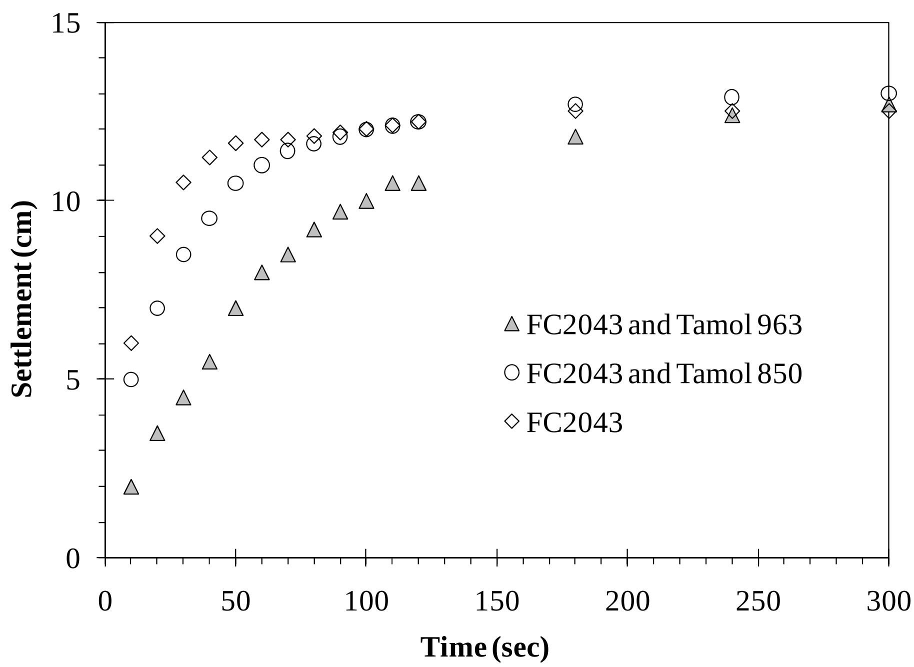
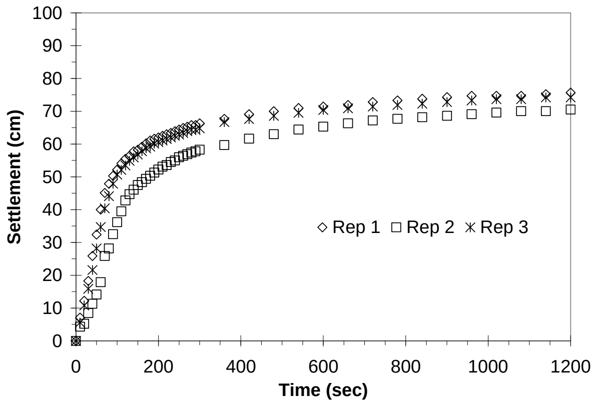


Figure 4.8. Protocol 2 Small Settling Column Test Results for Settling Versus Time

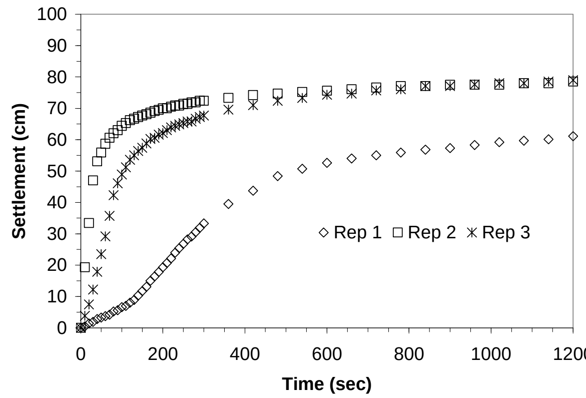
4.4.2 Large Column Test Results

Twenty-two large column settling tests were conducted with ten different polymer dosage rates. All large column testing incorporated *Soil 3* in freshwater. Settlement versus time plots for all large column testing are shown in Figure 4.9. Figures 4.9a through 4.9e show repeat testing at a given dosage rate, while Figure 4.9f shows testing as a function of dosage. The average behavior was plotted in Figure 4.9f for dosage rates where multiple tests were conducted. Three distinct zones were observed in the data of Figure 4.9f: 1) 0.5 to 1.0 kg/DT_m; 2) 1.25 to 3.5 kg/DT_m; and 3) 5.5 to 7.5 kg/DT_m.

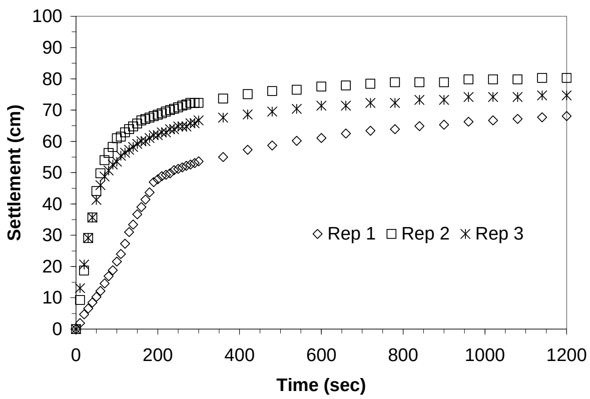
Figure 4.10 shows photos of the flocculated soil in the large column. It can be seen that the dewatering polymer has a pronounced effect on the material and is efficient for rapid separation of a substantial portion of water. Figure 4.11a through 4.11c plot settling velocity versus time incorporating varying amounts of data; 90 seconds was the maximum amount of data that could be incorporated since after this time the curves had noticeably broken as seen in Figure 4.9. Settling velocity in the large column was highly variable. Mixing energy could have played a role due to the introduction of the material into the column. The mixing energy between tests could have been variable as pouring material into a column lends itself to variability. Settling velocities incorporating only early data points (e.g. 20 seconds) were the highest and decreased as more points were added. This is likely attributed to soil particle contact as separation occurs. Variability reduced as more data points were included in the calculation.



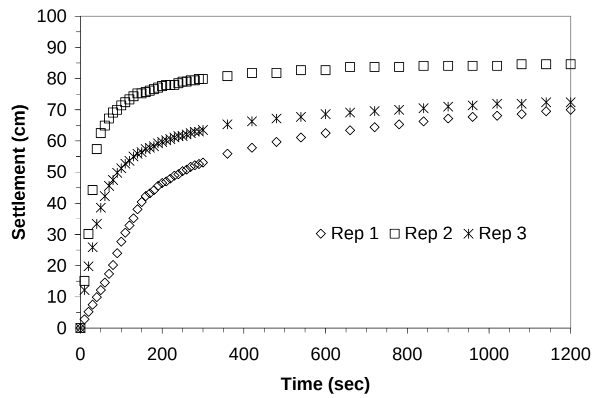
(a) Soil 3-1.25 kg/DT_m



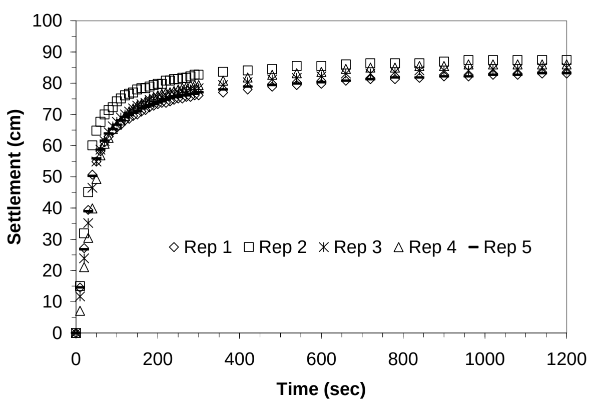
(b) Soil 3-2.0 kg/DT_m



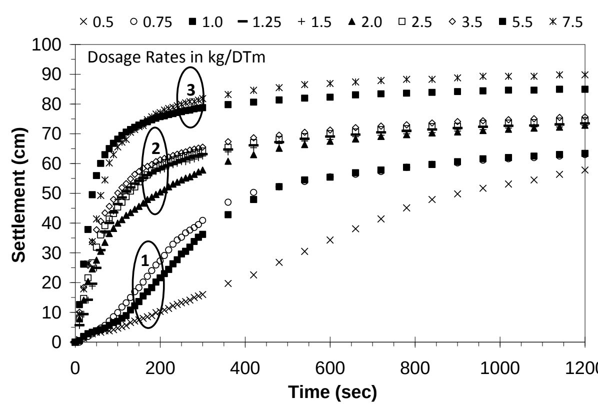
(c) Soil 3-2.5 kg/DT_m



(d) Soil 3-3.5 kg/DT_m



(e) Soil 3-5.5 kg/DT_m



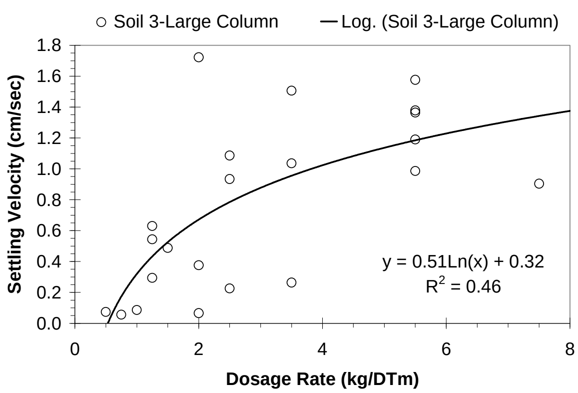
(f) Soil 3-All Dosage Rates

Figure 4.9. Large Settling Column Test Results for Settling Versus Time

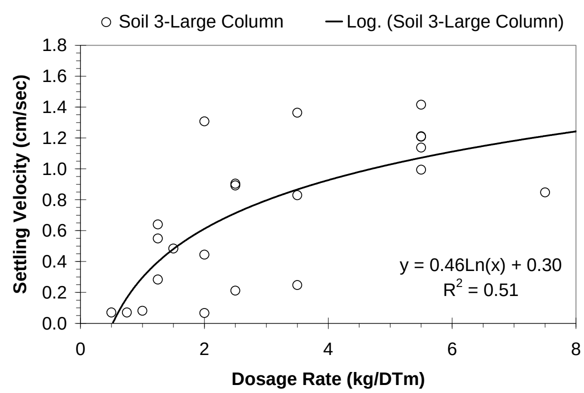
(a) Early Part of Test

(b) End of Test

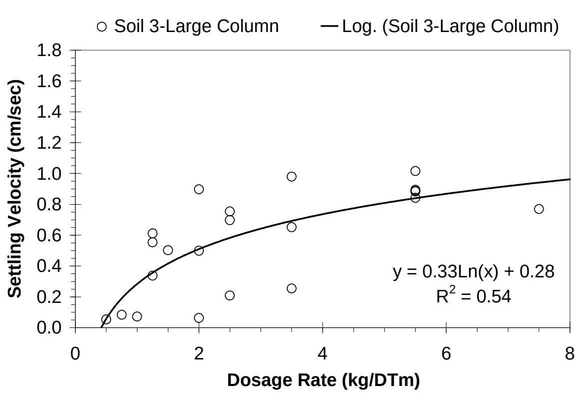
Figure 4.10. Photos of Soil Flocculation and Dewatering in Large Column



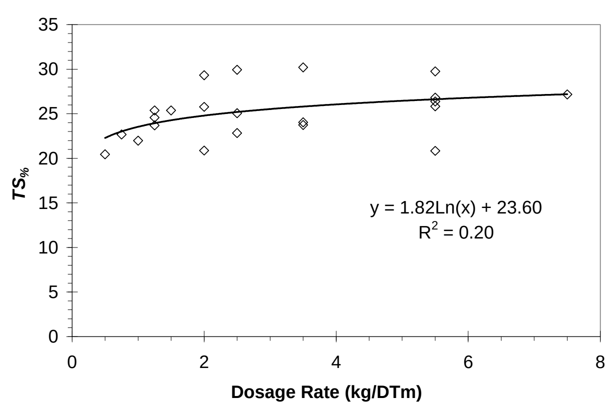
(a) Settling Velocity (20 Seconds)



(b) Settling Velocity (50 Seconds)



(c) Settling Velocity (90 Seconds)



(d) $TS_{\%}$

Figure 4.11. Large Settling Column Test Results for Settling Velocity and $TS_{\%}$

4.4.3 Comparison of Small and Large Column Test Results

Both the large column and small column had three zones of settlement versus time for a wide range of dosage rates. The zones were much more defined in the large column than in the small column. The zones exhibited some overlap but since the same dosage rates were not necessarily tested for the small and large columns no specific inferences can be made. In general the same patterns were observed in settlement versus time as a function of dosage rate.

Figure 4.12 plots trend lines from small and large column testing. An envelope of settling velocity versus dosage rate was obtained with the fastest settling rate occurring in the large column during early portions of the test. This result is not surprising since it is the environment where flocculated soil can fall through water with the least resistance. Test results for the small column at 20 sec and the large column at 50 sec were very similar. Large equipment would likely provide a large area for settlement thus providing an optimum environment for settlement (i.e. settling velocities at or greater than the large column at 20 sec). In absence of field data the settling velocity behavior of the small column at 20 sec and the large column at 50 sec are recommended.

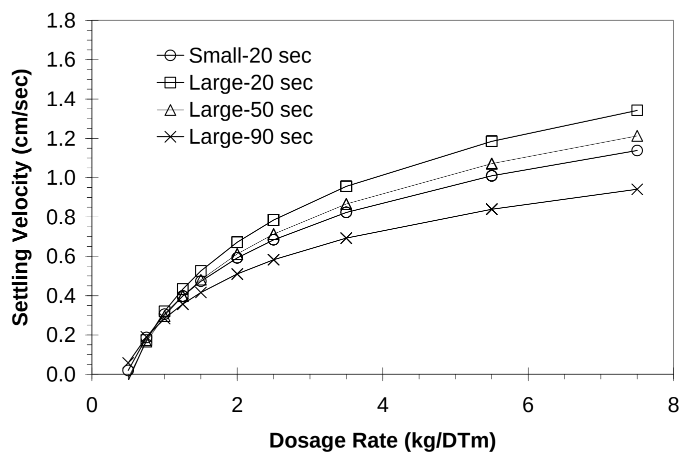


Figure 4.12. Settling Velocity Summary

In the small column *TS%* could be doubled in freshwater for *Soil 3* from 10 to 20 in 5 minutes using approximately 1.6 kg/DT_m of polymer (based on Figure 4.7b trendline). In the large column *TS%* was approximately 25 for the same dosage rate after 20 minutes (based on Figure 4.11d trendline). In large quantities and with reasonable detention times (e.g. 30 to 45 min) *TS%* of 30 is not perceived to be difficult with typical equipment. *TS%* of 30 was achieved in 20 minutes in some of the large settling column experiments.

Table 4.10 provides coefficient of variation (*cov*) results for all settling column testing with three or more replicates (i.e. *n* of 3 or more). The small column was substantially less variable, and with one exception provided consistent results. The small column appears capable of providing a practical means of evaluating settling velocity, though calibration is needed with field mixed materials.

Table 4.10. Statistical Test Results of Large and Small Column Testing

Column	Soil-Water	*n*	Dosage (kg/DT_m)	*cov* $TS_{\%}$	V_{20}	V_{50}	V_{90}
Large	3-Fresh	3	1.25	3.4	35.7	37.8	28.8
	3-Fresh	3	2.00	16.8	122.1	104.9	85.7
	3-Fresh	3	2.50	14.0	61.3	59.2	54.1
	3-Fresh	3	3.50	14.0	67.0	68.6	57.9
	3-Fresh	5	5.50	12.5	17.1	12.8	7.3
Small	3-Fresh	3	1.25	4.8	43.8	---	---
	3-Fresh	3	4.50	1.6	1.1	---	---
	3-Fresh	5	5.50	4.5	4.3	---	---
	3-Fresh	3	6.50	5.7	5.4	---	---
	3-Salt	3	2.50	3.5	2.6	---	---
	3-Brackish	3	2.50	1.5	1.7	---	---
	1-Fresh	3	6.00	2.0	3.4	---	---
	2-Fresh	3	12.00	3.5	5.1	---	---

Note: V_{20}, V_{50}, and V_{90} are settling velocities at 20, 50, and 90 seconds, respectively.

4.5 Standard *Geotube*® Dewatering Test (*GDT*) Results

Thirteen standard *GDT* tests were performed during the course of this research. Two variations of the test were used. Primary differences included quantity of material and slurry batching. The data is provided in the remainder of this section.

4.5.1 *GDT Standard Method 1* Test Results

GDT Standard Method 1 was performed at the *Ciba Corporation* laboratory in the presence of the MSU research team. Table 4.11 provides pertinent test properties. FC2043 polymer was used at a rate of 1.5 kg/DT_m (3 lb/DT). The dosage rate for this experiment was the lowest quantity that would provide visually acceptable solids settling.

At the conclusion of the test (120 min of drainage) the *pillow* was cut open and five full depth samples approximately 76 mm diameter were taken. One sample was in the middle of the *pillow* directly under the standpipe, and the other four samples were taken near the corners but far enough from the corners where a moderate thickness of material was present. Table 4.12 summarizes test results. The percent solids appeared to increase with cake thickness and the repeated shear of the solids did not appear to affect the yield stress. Repeated shear of the solids in the viscometer simulates passage through pumps.

Table 4.11. Sample Characteristics for *GDT Standard Method 1*

Characteristic	Result
Water	Brackish (Seawater and Rainwater)
Soil	*Soil 2*-New Orleans, LA
pH	7.25
Physical	Brown, Imperceptible Odor
Initial Percent Solids	11.51%
SG_{Slurry}	1.092

Sample breakdown (bleeding) was not observed indicating the major challenge with this material would be initiating movement and being able to sustain the needed energy. As a reference, typical mining operations incorporating centrifugal pumps are generally limited to pumping material with yield stresses of 100 Pa or less. This material would be limited in terms of the types of pumps that would be adequate and depending on the pumps available, the amount of drainage might have to be limited. Positive displacement pumps (described elsewhere in the research) are one of the viable options for pumping the material; perhaps they are the only viable option.

Table 4.12. *GDT Standard Method 1* Results of *Soil 2*

Sample	Cake Depth (cm)[1]	Final $TS_{\%}$ (%)	Yield Stress (Pa) After Plunging Cycles 20	50	100
Center	5.0	40.5	2,830	2,830	2,840
Corner	4.5	40.1	2,830	2,830	2,830
Corner	4.0	39.6	2,800	2,790	2,780
Corner	3.0	38.2	2,740	2,740	2,740
Corner	2.5	36.5	2,690	2,680	2,670

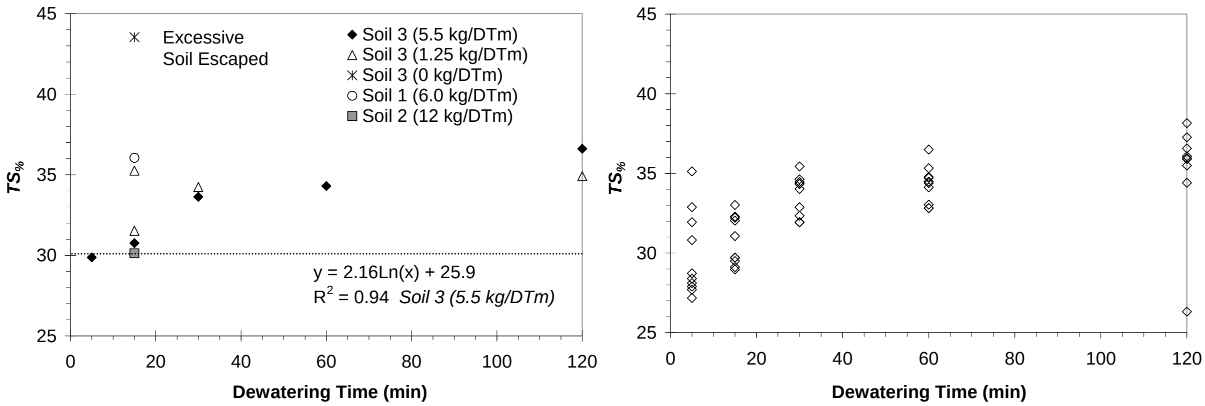
1: Cake depths were taken 16 hours after sampling so their only significance is relative comparison.

4.5.2 *GDT Standard Method 2* Test Results

Twelve *GDT* tests were performed using *Standard Method 2*. These tests were performed for three primary reasons: 1) investigate solids content as a function of time, polymer dosing, and soil type as this data is not readily available in research literature; 2) determine parameters needed in the *GDT* test to dewater the materials investigated in this research from $TS_{\%}$ of 10 to $TS_{\%}$ of 30; and 3) obtain polymer dosed material for cement stabilized testing provided in Section 4.7. Results of testing are found in Figure 4.13.

Figure 4.13a plots the average of the ten measurements taken throughout the geotextile tube as described in Chapter 3. Figure 4.13b plots all individual data points for *Soil 3* at the optimum dosage rate. The same trend is observed as when the average value is used, albeit with a noticeable amount of variability within individual measurement locations.

An immediate observation was that $TS_{\%}$ of 30 was achieved very quickly and could be achieved for all soils. *Soil 3* was essentially able to achieve $TS_{\%}$ of 30 after only five minutes of dewatering when using the optimum dosage rate from gravity flow drainage testing. Collection of data earlier than five minutes would be impractical using the methods employed in this report since it took upwards of four minutes to introduce all material into the *pillow* and allow time for all of the material to exit the standpipe. Since removal of such a high quantity of water occurred so quickly, the test is not believed to simulate the behavior within a large geotextile tube in terms of time to dewater soil from $TS_{\%}$ of 10 to $TS_{\%}$ of 30. The usefulness of the data thus is limited to general trends.



(a) Average of 10 Pts *(b) Soil 3 (5.5 kg/DTm) Raw Data*

Figure 4.13. GDT Test Results in Absence of Material Removal

Soil 3 at 5.5 kg/DT_m demonstrated logarithmic behavior; the equation is shown in Figure 4.13a in absence of the trendline to make data more visible. At 1.25 kg/DT_m, the same overall behavior is observed if the highest $TS_{\%}$ at 15 minutes is neglected. Note 1.25 kg/DT_m was selected considering equipment limitations and settling column testing. At 15 minutes, it can also be observed that *Soil 2* was the least effectively dewatered and *Soil 1* was the most effectively dewatered. The large settling column exhibited the same behavior. If organic content versus dewatering effectiveness were plotted, the trend would be that the higher the organic content the less effectively the material was dewatered in terms of $TS_{\%}$. This behavior is logical since organic materials have affinity for water and contain more water at a given consistency.

Test results from standard methods 1 and 2 agreed with each other in general terms. *Standard Method 1* dewatered *Soil 2* to an average value of 30% at 120 min whereas *Soil 3* was dewatered to 35 to 37% using *Standard Method 2*. More material was used in *Standard Method 2*, which would, in general, make dewatering more difficult and reduce $TS_{\%}$. *Soil 2* has more organic material than *Soil 3* which would also contribute to $TS_{\%}$ of *Soil 3* being less than *Soil 2*.

Solids escaped the *pillow* freely during the test with no polymer; there was not a significant amount of material remaining in the *pillow* at the conclusion of testing, making the test result of little physical meaning relative to the other tests where relatively clean water was escaping the *pillow*. Figure 4.14 is an example. No comparison should be made with the test that did not use polymer to any other testing as the *GT 500* material did not retain particles in absence of flocculation for the fine grained material. To use an untreated soil, an optimization process can be required between soil particle and geotextile opening sizes (e.g. Koerner and Koerner 2006).

(a) Polymer Dosed Soil 3

(b) Non-Polymer Dosed Soil 3

Figure 4.14. Visual Comparison of Polymer Treatment Effectiveness

GDT testing supported the position that the soils tested can be dewatered from $TS_{\%}$ of 10 to 30 relatively easily. Trends were the same in *GDT* and large column testing. Lower polymer dosage rates provided acceptable performance; there was not a substantial difference in $TS_{\%}$ for *Soil 3* when the dosage rate was reduced from 5.5 to 1.25 kg/DT_m.

4.6 Material Removal Test Results

One *GDT* test was conducted to simulate material removal using *Soil 3* after 15 minutes of dewatering time and 5.5 kg/DT_m polymer dosing. The exit port installed as discussed in Chapter 3 was opened after 15 minutes of dewatering. There was approximately 20 cm of head on the material at the time of plug removal with an estimated $TS_{\%}$ of 30 based on previous testing. This resulted in minor amounts of material leaving the *pillow*. The water column was slowly filled and material began to readily exit the pillow at 35 to 40 cm of pressure head. The scale of the *GDT pillow* was deemed too small to further evaluate material removal. The remainder of the material removal investigation was performed using the large column as discussed in the remainder of this section.

Material removal analysis of large column data used conservation of mass according to Eq. 4.1. The inner diameter of the column was 19 cm, while the inner diameter of the exit was 1.9 cm. Using Eq. 4.1 and the aforementioned dimensions it can be seen that the exit velocity was 100 times the velocity in the column.

$$A_1V_1 = A_2V_2 \tag{4.1}$$

A_1 = Area of column (283.5 cm^2)
A_2 = Area of exit (2.835 cm^2)
V_1 = Velocity of material while in column
V_2 = Velocity of material while exiting column

Results of material removal testing can be seen in Figure 4.15. From a practical perspective, no substantial difference was observed between water and *Soil 3* dosed with 5.5

kg/DT_m of polymer and dewatered to $TS_{\%}$ of 30 in terms of velocity when removed from the large column via gravity induced pressure. This would indicate that material dewatered inside a geotextile tube (or similar approach) using polymers would flow from geotextile tube via gravity pressure for typical size tubes. The column diameter was intentionally made large in comparison to the exit diameter as this would be the case for a geotextile tube with a commercially available pipe connected to it. Wall friction effects would not be expected to drastically affect behaviors in these conditions. Note that pumping the same material through pipes and the associated friction losses were not quantified in that the purpose of this experiment was to evaluate if the material would gravity flow from a geotextile tube under pressures that would be generated by the tube itself. The result was the material would flow at $TS_{\%}$ of 30. Note, however, the yield stress results in Table 4.12 as they indicate flowability could be compromised if the material were allowed to dewater too long prior to removal.

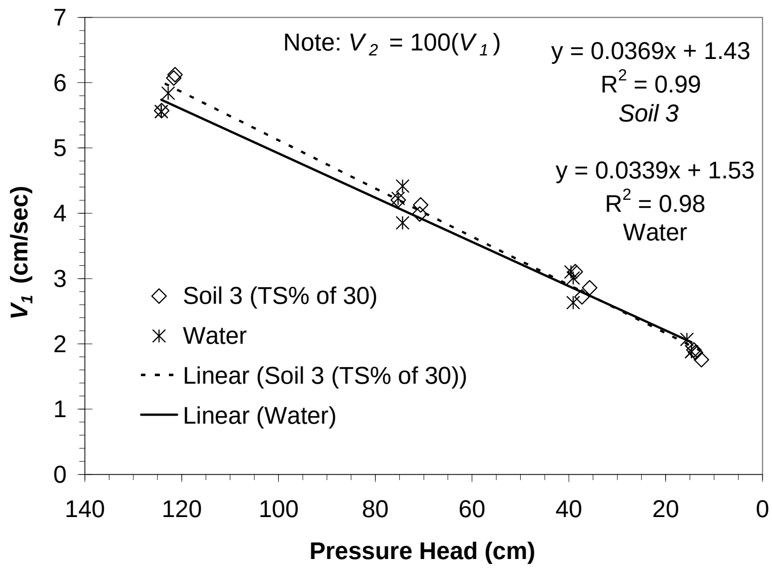


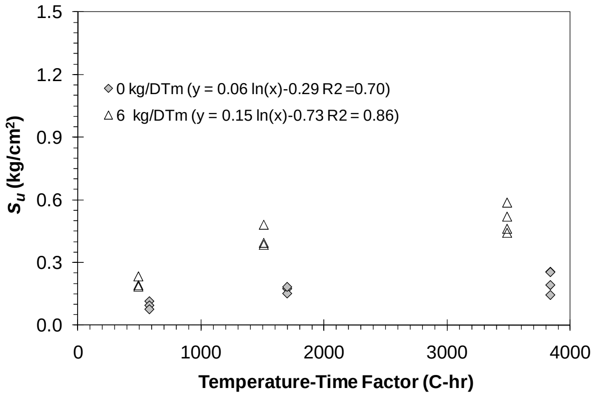
Figure 4.15. Material Removal Test Results in Large Column

4.7 Polymer Dewatered and Cementitious Stabilized Test Results

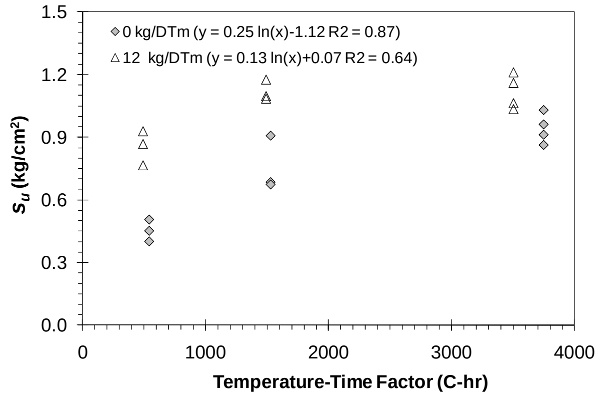
4.7.1 *UC* Test Results

Slurry unit weight was not noticeably affected by addition of polymer, and the unit weight of the test specimens resembled the vibrated unit weight of the material indicating few air voids in the specimens during testing. Figure 4.16 contains shear strength results for all polymer dewatered *UC* suites and corresponding control testing.

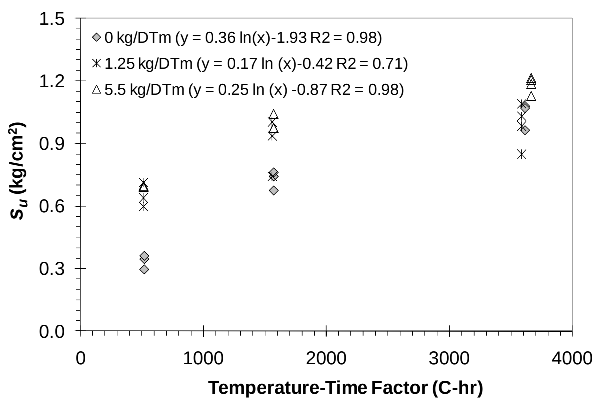
Figure 4.16a plots *Soil 1* with *Th T III* cement and shows 6 kg/DT_m dosed specimens to be substantially stronger than control specimens at all test times. Figure 4.16b plots *Soil 2* with *Th T III* cement and shows the 12 kg/DT_m dosed specimens were stronger than the control specimens at all test times. At temperature-time factors exceeding 3,000 C-hr, the polymer dosed specimens were only moderately stronger than the control specimens whereas at temperature-time factors less than 2,000 C-hr the polymer dosed specimens were considerably stronger than 0 kg/DT_m dosed control specimens.



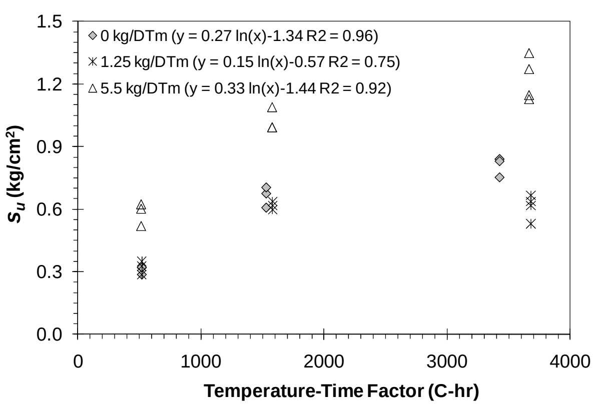
(a) Soil 1 with Th T III



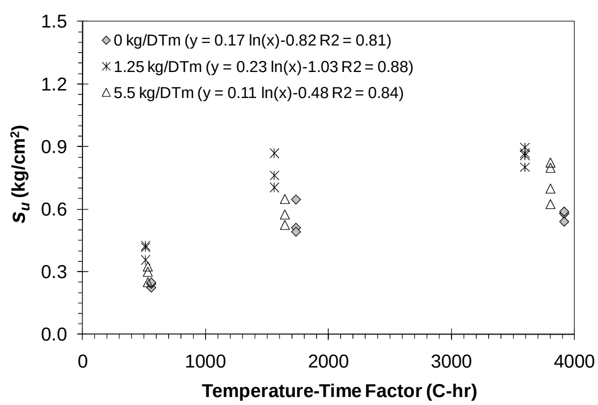
(b) Soil 2 with Th T III



(c) Soil 3 with Th T III



(d) Soil 3 with A T III



(e) Soil 3 with SC1

Figure 4.16. Results of UC Testing

Figure 4.16c plots *Soil 3* with *Th T III* cement and shows both polymer dosage rates strengthened the specimens at temperature-time factors less than 1,000 C-hr. Between 1,000 and 2,000 C-hr, the 5.5 kg/DT_m dosed specimens remained noticeably stronger with the 1.25 kg/DT_m specimens being only moderately stronger than the control specimens with no polymer. At temperature-time factors exceeding 3,000 C-hr, the 5.5 kg/DT_m specimens were moderately stronger than the 0 kg/DTm specimens while the 1.25 kg/DT_m specimens had essentially the same strength as the 0 kg/DT_m specimens.

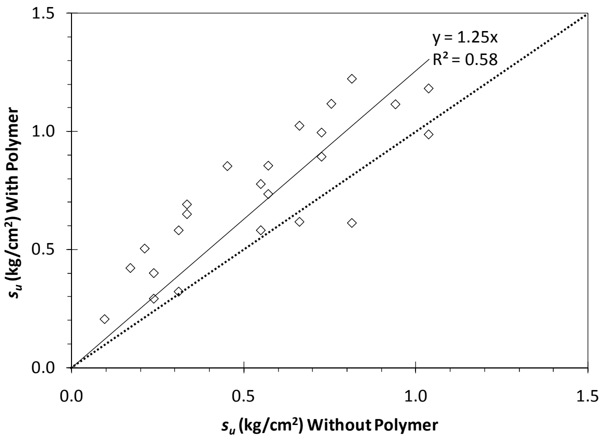
Figure 4.16d plots *Soil 3* with *A T III* cement and shows considerably higher strength in the 5.5 kg/DT_m with respect to the 0 and 1.25 kg/DT_m suites. Less than 2,000 C-hr the 0 and 1.25 kg/DT_m suites are essentially the same shear strength. At temperature-time factors values exceeding 3,000 C-hr, the 1.25 kg/DT_m polymer dosed suite had a reduced shear strength with respect to the control suite with no polymer.

Figure 4.16e plots *Soil 3* with *SC1* cement and unlike the other four test conditions the highest polymer dosage did not out perform the other cases. The 1.25 kg/DT_m dosage rate out performed the 0 and 5.5 kg/DT_m dosage rates. The 5.5 kg/DT_m rate performed at to slightly better than the 0 kg/DT_m rate; note the 5.5 kg/DT_m suite shown is a re-test as the original test results were questionable.

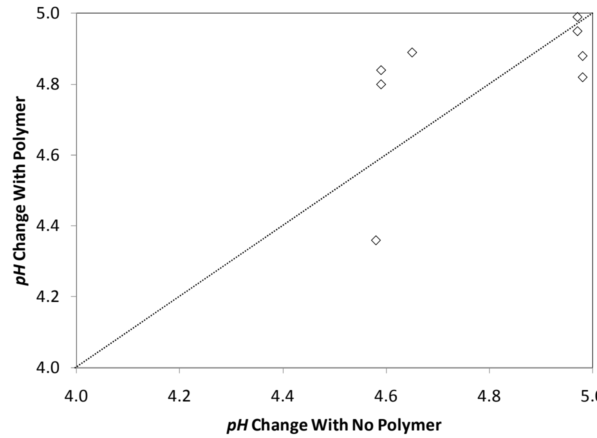
Figure 4.17 compares the average shear strength of polymer and non-polymer treated materials by neglecting differences in maturity within the three distinct sets of data in each plot in Figure 4.16. Taking Figure 4.16a as an example, the average shear strength of the 0 kg/DT_m dosage rate at 578 C-hr (0.10 kg/cm^2) was plotted on the *x*-axis, and the average shear strength of the 6 kg/DT_m dosage rate at 490 C-hr (0.20 kg/cm^2) was plotted on the *y*-axis. The same procedure was used with elastic modulus (*E*) and maximum strain (ε_{max}). A single data point was measured for *pH* change during fabrication of suite of test specimens.

Shear strength was improved as a result of the polymers; the trend line predicted a 25% shear strength increase though there was scatter in the data. Change in *pH* did not explain the increased shear strength as four of the polymer dosed suites had increased *pH* due to polymer addition while the other four suites experienced a *pH* reduction. Change in *pH* for all suites was within one logarithm (4 to 5), with the differences in polymer and non-polymer dosed suites being considerably less than one logarithm.

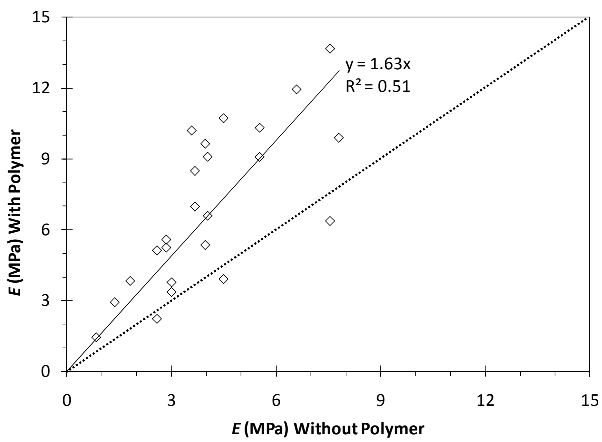
Elastic modulus was also improved as a result of the polymers; the trend line predicted a 65% elastic modulus increase though there was scatter in the data. As with shear strength, rarely did data plot below the line of equality. Maximum strain data was, in general, reduced as a result of polymer inclusion though there was no definable trend. Note the scale of Figure 4.17d as the range is only 2% strain. In summary, polymers made the stabilized soil specimens, stronger, stiffer, and slightly more brittle.



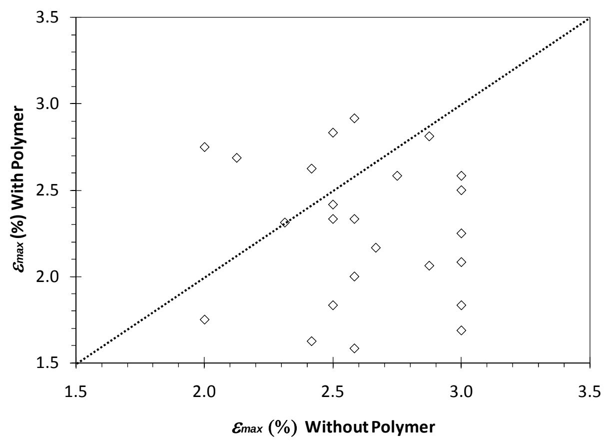
(a) Effect on Shear Strength



(b) Effect on pH Change



(c) Effect on Elastic Modulus

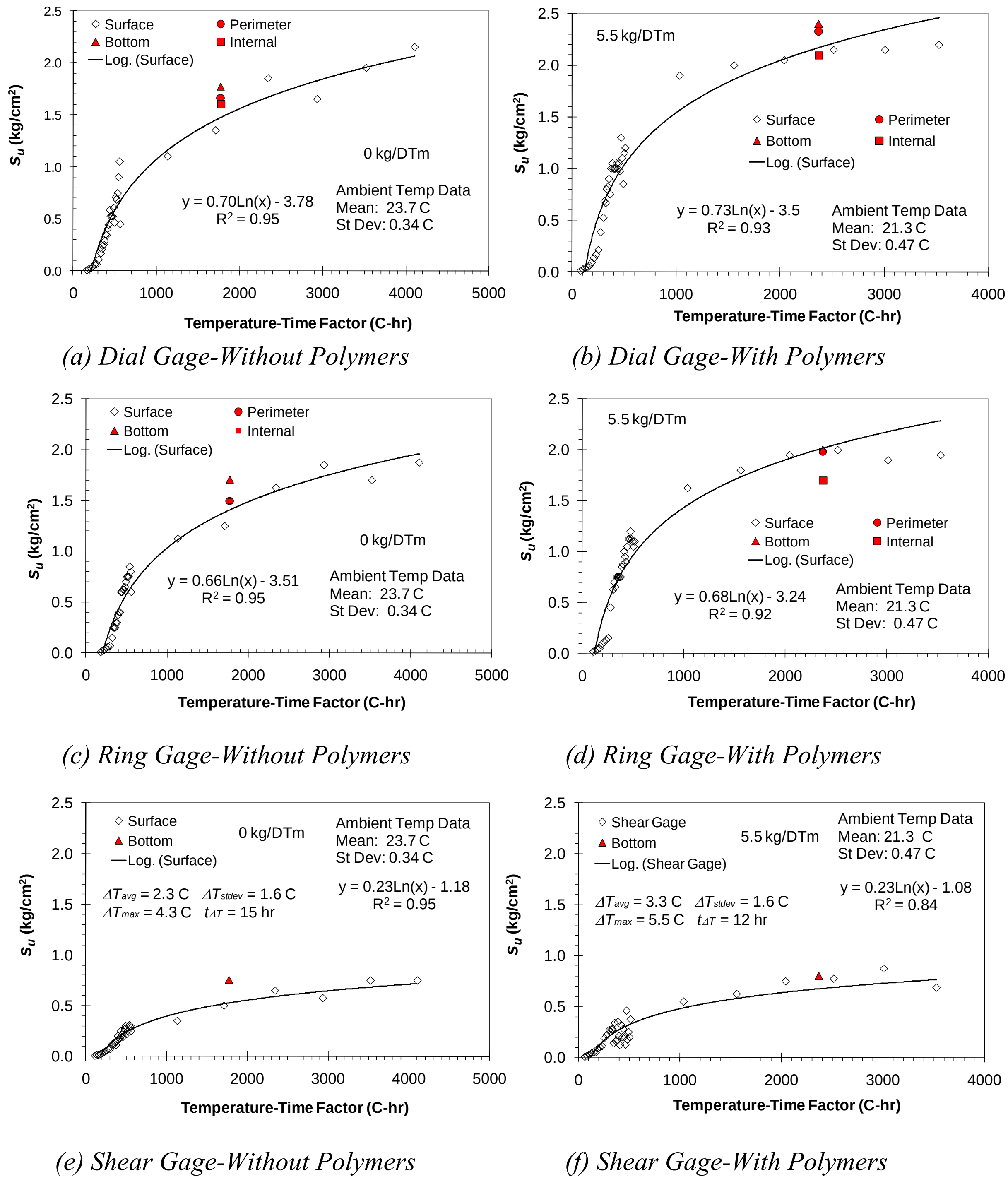


(d) Effect on Maximum Strain

Figure 4.17. Summary of Polymer Effect on Cementitious Stabilized Soils

4.7.2 Trial Test Results

Slurry unit weight was not noticeably affected by addition of polymer, and the unit weight of the test specimens resembled the vibrated unit weight of the material indicating few air voids in the specimens during testing. Figure 4.18 plots test results for all three hand held gages with and without polymers. Corresponding test devices were placed side by side for ease of comparison. Trend lines developed to predict shear strength versus temperature-time factor were not initiated until the specimens had a measurable strength, which took at or above 100 C-hr in many instances. Visually, the *Dial* and *Ring* test results are similar polymer to no polymer except the polymer treated materials appear to gain strength somewhat faster. Scatter of data was similar between the polymer treated and non-treated materials.



(a) Dial Gage-Without Polymers *(b) Dial Gage-With Polymers*

(c) Ring Gage-Without Polymers *(d) Ring Gage-With Polymers*

(e) Shear Gage-Without Polymers *(f) Shear Gage-With Polymers*

Figure 4.18. Results of Trial Testing of Soil 3 with Th T III at (15, 233)

Internal temperature was measured during testing and compared to room temperature above the specimens (*ΔT*) to observe the maximum temperature difference, average temperature difference, standard deviation of temperature difference, and the time from cement addition where the maximum temperature difference occurred ($t_{\Delta T}$). These results are shown on the *Shear* plots, but note this was only for convenience as the same slabs were used to perform all testing. Internal temperature was higher in the polymer treated specimens, providing evidence of improved exothermic reaction of the cementitious materials.

Figure 4.19 compares shear strengths of polymer treated and non-polymer treated materials with all four strength measurement techniques by plotting trend lines with respect to each other. Samples treated with polymer were stronger in all instances. *Dial* and *Ring* shear strengths were considerably higher than *UC* shear strengths, while shear strengths from the *Shear* device were lower than *UC* measured values. The trend of *Dial* and *Ring* gages measuring higher shear strengths than *UC* and *Shear* gages was observed and discussed in *SERRI Report 70015-006*.

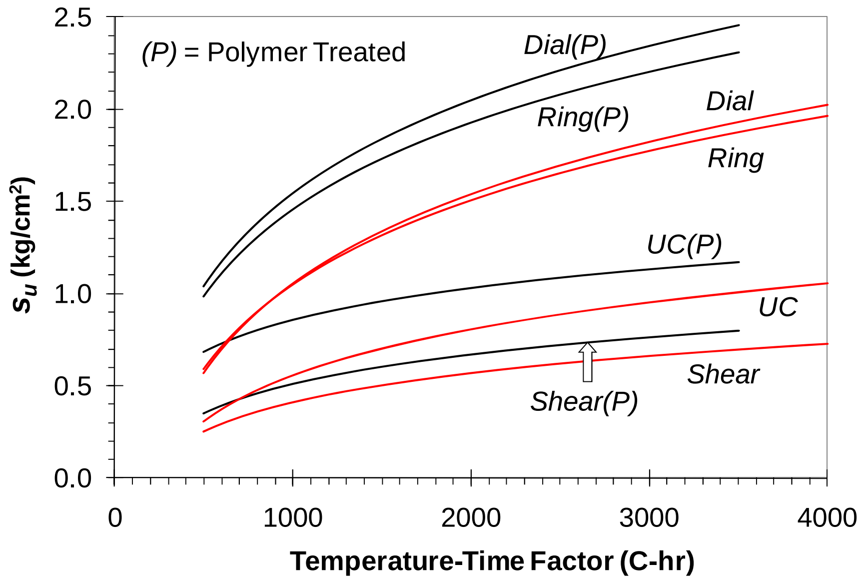


Figure 4.19. Results of All Soil 3 Testing with Th T III at (15, 233)

CHAPTER 5 - CONSTRUCTION PROCEDURES

5.1 General Construction Information

For construction purposes, the items of primary interest to this research were: 1) can a geotextile tube be used as a form of clarifier in emergency construction; 2) how many metric tons of dry solids can be achieved per hour with typically available equipment and what is a reasonable $TS_{\%}$ of this material; 3) what are reasonable polymer dosage rates for fine grained soils likely to be encountered in disaster response; 4) what are representative examples of equipment needed to use dewatered soil in emergency construction.

In all cases, a hydraulic dredge was the delivery mechanism considered in this report. The *2008 Geotextile Tubes Workshop* (Howard et al. 2009) included data related to a project referred to as *Millennium Plant* where a 160 kW Nomad III horizontal cutterhead dredge was pumping 11,000 Lpm at 10% solids. A pre-treatment $TS_{\%}$ of 10 was used throughout since it is a consistently achieveable value for dredging operations; it can be exceeded in many cases making it a reasonable to conservative choice. The pumping rate was taken as 11,000 Lpm or less.

5.2 Use of Polymers in Construction

On the site of a disaster area, selection of a reasonable range of dosage rates and polymer(s) applicable to the situation is not perceived to be a challenge. Gravity flow drainage tests, dewatering cone tests, or rapid dewatering tests are all candidates that require meager resources that can be brought to the site by one person. Testing could be performed during the period of time equipment was being mobilized and set up.

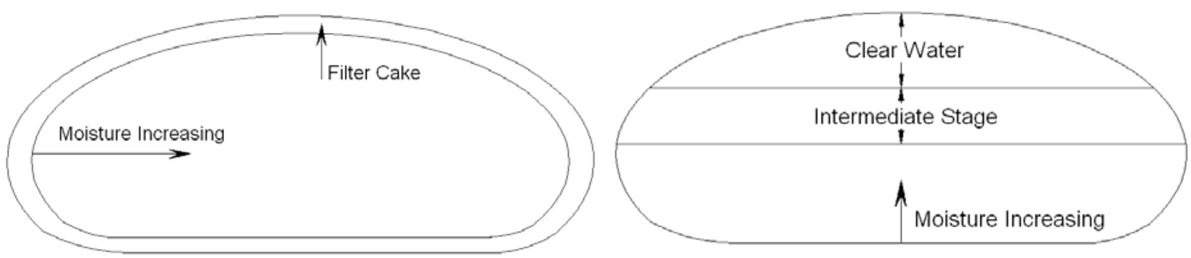
Equipment was identified that is portable and could be used in a practical response plan. Availability of sufficient quantity of equipment to supply enough polymers to produce ample amounts of emergency construction material is questionable. Portable equipment was found that could supply 31 to 62 kg of active polymer per hour depending on the specific equipment available. Clean water is a needed commodity that would be highly valued during a disaster. Section 2.2 provided detailed discussion pertaining to polymers that has not been repeated in this section.

Testing provided in Chapter 4 indicated dosage rates lower than optimum according to gravity flow drainage testing could be used to dewater soil from $TS_{\%}$ of 10 to 30 in a reasonable amount of time. *GDT* testing with 1.25 kg/DT_m performed similar to 5.5 kg/DT_m with *Soil 3*. Dosage of 1.25 kg/DT_m was within the acceptable range of equipment capacities (0.65 to 1.30 kg/DT_m). The amount of polymer available may not meet the demand even at a dosage rate reduced from the optimum gravity flow drainage rate.

5.3 Use of Geotextile Tubes in Construction

The intent of using geotextile tubes would be to increase $TS_{\%}$ from 10 to 30. The material in the tube would have to remain in a fluid condition (i.e. k_o of 1) to flow from the tube. A filter cake is believed to form inside a geotextile tube in absence of polymer modification based on review of literature. The filter cake thickness is likely too narrow to attempt to remove this material alone. The filter cake should be disrupted as much as possible to accelerate dewatering. With polymer modification multiple scenarios can exist. When filling a geotextile tube, localized settling can exist while localized turbulence can also exist in other portions of the same tube. As a result, there may or may not be a uniform layer of material with a higher solids content form inside a full scale geotextile tube with typical inlet port spacing (7 to 18 m).

A properly chemically treated material should settle out of suspension quickly and inhibit the formation of a large thickness of filter cake around the entire perimeter of the geotextile tube. Settlement of particles quickly due to the polymers provides a path more clear of obstructions relative to a circumferentially formed filter cake. Figure 5.1 provides general idealized behaviors that are believed to occur with and without polymer modification. The clear water shown in Figure 5.1 is estimated to be as deep as 20% of the depth of the tube.



(a) Description of Behavior w/out Polymer *(b) Description of Behavior w/ Polymer*

Figure 5.1. Moisture Conditions Within Geotextile Tube

If a geotextile tube were used to dewater material that is removed from the tube for use as an emergency construction material, two options are envisioned: 1) material would be gravity fed from extra ports installed near the bottom of the tube spaced a moderate distance apart on either side of the tube; or 2) material would be pumped from standard ports in the top of the geotextile tube. In either scenario, the geotextile tube would first be filled to a reasonable level with slurry from a hydraulic dredge. Once filled to a reasonable level, an operator would periodically check the outlet moisture content (either gravity flow from bottom or pumped from the top). Once the moisture content of the outlet had achieved an acceptable level (e.g. $TS_{\%}$ of 30) dewatered material would be removed from the tube while 10% solids slurry was being fed into the tube to replenish the tube. Provided the scenario of Figure 5.1b occurred, water could be pumped out of the top of the tube and discarded to allow for a higher inflow pumping rate.

The moisture content of the outlet material would have to be checked regularly with a rapid moisture measurement or pre-determined correlation and when it increased to an unacceptable level the options would be: 1) pause material removal if the geotextile tube was not near the design height and wait for moisture content to decrease while continuing to fill; or 2) pause material removal and filling of geotextile tube until an acceptable moisture content is achieved if the geotextile tube is near the design height. This cyclic procedure would be repeated during use of the tube. One likely flaw to the process would be material building in the tube in zones away from the outlet that were dewatered too much to be removed from the tube. This would be exacerbated during prolonged periods where no material removal was occurring. Vibration of the walls of the tube would lessen this potentially limiting behavior, though, likely prolonging but not stopping the eventual plugging of the tube. This tube would then have to be disposed of, which would require considerable resources.

Material removal could conceivably be enhanced by placing a geotextile tube in an inverted U shape. This would allow two pumps or outlet locations to be placed in the depressions on the sides, as well as increase consolidation pressure on this material. Since geotextile tubes are prone to roll while dewatering (friction is very low underneath the tube due to water flow during dewatering), lateral bracing could be necessary for this application. Steel frames are available to hold geotextile tubes in place while they are being filled.

Based on review of literature, laboratory testing, and the aforementioned hypothesized discussion, material removal from a geotextile tube is believed to be possible but not practical. Test data showed the material could flow from the tube as a result of internal pressure that would be present in a typical tube. The major flaw in the approach is believed to be material buildup eventually leading to a clogged tube that would be difficult to maneuver during disposal.

5.4 Use of Clarifiers and Similar Equipment in Construction

Representatives of *Clearwater Industries* were contacted by the research team and they indicated that achieving $TS_{\%}$ of 30 was very reasonable with the clarifier discussed in Chapter 2 in a fairly expedient manner and that $TS_{\%}$ of 40 to 52% has been achieved. Using the properties of the *Model 2000 Portable Water Clarifier* and Eq. 5.1, capacity estimates were made for the disaster. The following inputs result in w_{se} of 48 metric tons per hour: Q of 7,500, γ_w of 1, SG_{Slurry} of 1.07, and $TS_{\%\text{-}In}$ of 10. A solids content of 10% entering a clarifier is very reasonable from a dredge or similar device and can be exceeded with the proper conditions. Therefore, the w_s value calculated could be exceeded under the proper conditions. Note, however, the calculations considered the maximum entering flow rate.

$$w_{se} = (Q)(\gamma_w)(SG_{Slurry})(TS_{\%-In})(6E^{-4}) \tag{5.1}$$

Where,

w_{se} = weight of solids exiting clarifier (metric tons per hour)
Q = flow rate entering clarifier (Lpm)
γ_w = unit weight of water (kg/liter)
SG_{Slurry} = specific gravity of slurry entering clarifier
$TS_{\%\text{-}In}$ = total solids expressed as a percent entering clarifier

For an exiting $TS_{\%}$ value of 30, the clarifier would produce 160 metric tons per hour of slurry for use as an emergency construction material (after cementitious stabilization discussed in complimentary research) under the conditions provided. This is a moderate amount of construction material provided it could be developed in a manner that was not exhaustive at the disaster. The operational weight of the clarifier is 52,000 kg, which drastically affects the ability to place it on a barge and use it within the perimeter of a flooded area. It can be accomplished, though the use of resources might be too exhaustive relative to other approaches (e.g. positive displacement pumps). Use of these technologies might be better suited for more critical applications where less material is to be treated (e.g. contaminated sediments).

5.5 Estimated Construction Parameters

The optimal dosage rate from gravity flow drainage testing of *Soil 2* of 12 kg/DT_m in freshwater would almost certainly be impractical in a disaster; excessive polymer would be required. The optimal dosage rates from gravity flow drainage testing of *Soil 1* and *Soil 3* in freshwater would likely be impractical. Maximum dosage rates of 31, 47, and 62 kg of polymer per hour were available from portable equipment based on review of current practice found in Chapter 2. The maximum dosage a single unit could provide to the *Model 2000* clarifier would be 0.65, 0.98, and 1.30 kg/DT_m, respectively. As seen, these levels are drastically below the optimal dosage rates for freshwater, and moderately below the optimal gravity flow drainage dosage rates in saltwater. In saltwater, multiple units would be conceivable to produce the optimal dosage, or a lower dosage could be used that could produce acceptable results.

Based on laboratory test results found in Chapter 4, dosage rates plausible for the portable equipment identified could provide acceptable performance. The equipment would need to operate at full polymer dosing capacity. Performance of the smaller units (0.65 kg/DT_m) serving the portable clarifier might not provide acceptable performance at full capacity of the clarifier requiring inflow rates to be reduced. The larger units should be able to operate the clarifier at full capacity when polymer dosing is at full capacity. Multiple polymer dosing units serving one portable clarifier is also an option.

CHAPTER 6 – SUMMARY CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Rapid dewatering of fine grained soil for immediate re-use as an emergency construction material (stabilized with cementitious material) was discussed in this report. The research is part of a larger study related to disaster recovery. A literature and practice review was conducted related to available technologies and equipment that was used to develop an experimental program. The experimental program consisted of multiple test methods to determine effects of polymer dosage rate on settling velocity and dewatering effectiveness. Construction scenarios were investigated using the information from literature and practice review alongside laboratory test results. The remainder of this chapter provides conclusions and recommendations from the research.

6.2 Conclusions

- Dewatering soil for use as an emergency construction material appears feasible but is probably impractical based on the research conducted. A key to the conclusion that the approaches discussed in this report are likely impractical was the work related to the use of positive displacement pumps (discussed in *SERRI Report 70015-008*), which appear to more effectively accomplish an equivalent purpose.
- The quantity of polymer required for development of substantial quantities of emergency construction material would very likely become impractical for fine grained high plasticity slurries.
- Use of polymers in high need applications could improve disaster recovery. Material and portable equipment quantities make approaches such as contaminated sediments highly suitable. The material could be dewatered with polymers, stabilized with cementitious material, placed in a geotextile tube as a temporary structural element, and then removed once disaster recovery ceases. The material would be contained during the critical period while used in an isolated and beneficial manner prior to expedient disposal at a convenient time. Containment of contaminated materials in this environment would not be a large extension of existing applications with proven performance records.
- Material removal from a geotextile tube was not found to have advantage for emergency construction material development.
- Test data provided in this report showed that $TS_{\%}$ of 25 was easy to achieve, which was indicated by Fowler et al. (2007). $TS_{\%}$ of 30 is believed to be achieved relatively easily with portable equipment and polymer dosing capacities.
- Lower dosage rates relative to optimum gravity flow drainage testing appear to provide acceptable settling velocities and total solids ($TS_{\%}$) for the materials investigated. A dosage rate on the order of ¼ of the optimum rate from gravity flow drainage testing provided acceptable performance for the one soil tested in this manner. Note, the aforementioned statements do not consider properties of effluent water.

- Portable clarifiers exist that could be beneficial in a disaster but they are extremely heavy when in operation. Placement on a barge to use for emergency construction material development would pose logistical challenges likely in excess of the benefits. A conveniently located river might offset some challenges.
- It could be easier to slurry soil to the desired $TS_{\%}$ at the edge of the flooded area and pump it to the construction location than to dewater soil from floating platforms.
- The need for fresh water is a potential problem for dewatering large quantities of material and supports dewatering contaminated material. Also, limited portable equipment and polymer quantities make using the approach for contaminated sediments more viable.
- The test methods used to measure settling velocity show promise in advancing the use of polymers for fine grained soil dewatering.

6.3 Recommendations

- Test settling velocity in a large tank resembling full scale as close as possible. The original slurry should be placed in the tank and mixed with discretely spaced mixers or circulating pumps, polymer added, the slurry re-mixed, and the dewatering test commenced. This data would provide additional insight into the settling velocity of polymer treated slurries with appreciable amounts of solids (e.g. $TS_{\%}$ of 10).
- In the event one wanted to further investigate removal of material from a geotextile tube, a pilot scale demonstration should be performed prior to full scale testing. An example of a pilot scale test (no material removal) is shown in Figure 6.1.

Figure 6.1. Pilot Scale Dewatering Test

- Pump material from field dewatering equipment into a tall tank and monitor settling velocity. This would provide a direct assessment of full scale field mixed material settling in a representative environment that could be used to assess the needed mixing energy in the laboratory to simulate this environment. Calibration data of this nature would allow either the large column or small column test investigated in this report to be used for material selection and dosing requirements in a more effective manner.

- Data from this research indicates that taking soil slurry and dewatering it from $TS_{\%}$ of 10 to 30, introducing cementitious material, and pumping the pre-mixed stabilized slurry into a geotextile tube (material not to be removed) has promising application. Other logistical steps should be investigated as there is likely a more efficient method in which to apply the concept identified in this research effort. As an example, a significant portion of water was removed prior to addition of cement to provide a more volumetrically stable material and to minimize the amount of cementitious material that might be wasted if mixed with $TS_{\%}$ of 10 and some of the cement was carried away with the excess water as it left the geotextile tube. Another rational for removing a portion of the water was that the cementitious material could conceivably blind the geotextile tube and result in a fill material with little shear strength and high volume instability yet with the same amount of cementitious material used (likely the most expensive component of the process).

CHAPTER 7 - REFERENCES

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