DEWATERING SEWAGE SLUDGE WITH GEOTEXTILE TUBES

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ABSTRACT: Municipal sewage sludge was place in geotextile bags for the purpose of evaluating the dewatering and consolidation capabilities of large geotextile tubes and effluent water quality. A proposed ASTM test method for determining the flow rate of suspended solids from a geotextile containment system for dredged material was used to conduct tests to determine the efficiency of different combinations of geotextile filters. Prior to filling the large geotextile tube, two small geotextile bags 48 inches in circumference and 70 inches long were supported vertically in a wooden frame and filled to a depth of about 60 inches or about 48 gallons of sewage sludge from the primary sludge digester. As water passed through the geotextile bag, samples were collected during, immediately after and for several days to determine the total percent suspended solids (TSS), heavy metals, and bacterial count. The test results indicated significant consolidation or reduction in the volume of the sludge volume in the bag. There was also a significant reduction in the TSS, heavy metals, and bacterial count in the effluent water. These test results led to filling a large geotextile tube 15 ft wide, 30 ft long and filled to a height of 5 ft with sewage sludge.

The quality of pore water or effluent passing through the geotextile container systems proved to be environmentally acceptable for subsequent discharge into the Mississippi River and/or return to the treatment plant.

This new and innovative technology has been successfully used to dewater fine grained, contaminated dredged material that contained dioxins, PCB's, PAH's, pesticides and heavy metals for Miami River and the Port of Oakland, CA. This is the first successful use of geotextile tubes for dewatering sewage sludge for beneficial uses in the United States. Research using this process for dewatering pork and dairy farming waste, paper mill waste, fly ash, mining waste, chemical sludge lagoons and several other waste streams is being conducted by Dr. Tim Stark, University of Illinois.

This concept of containing sewage sludge has proven to be construction-practical, technically and economically feasible and environmentally acceptable.

Keywords: Geotextiles containers, geotubes, bags, sewage sludge, dewater, consolidation, dioxins, PCB, PAH, heavy metals, pesticides, disposal, beneficial uses

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1. INTRODUCTION

Purpose. The purpose of this demonstration test was to evaluate the dewatering and consolidation capabilities of large geotextile tubes for municipal sewage sludge and the water quality of the effluent passing through the geotextile filter fabric.

Scope. The scope of this report is to present the results of the laboratory and field tests, to evaluate the filling methods and techniques, and to evaluate the consolidation and dewatering behavior of a geotube filled with sewage sludge.

Background. The United States Environmental Protection Agency and the Mississippi Department of Environmental Quality have restricted the use of many types of waste lagoons such as those operated by municipal drinking water and sewage waste water treatment facilities. They have issued orders to restrict the use of these facilities, but have failed to provide an economical solution for future waste disposal.

2. BACKGROUND AND CASE HISTORIES

Since the late 1980's, several thousand geotextile bags, tubes and containers ranging in sizes from 1 to 4000 cubic meters have been successfully filled with a variety of fill materials in the Netherlands, Germany, France, Japan, Brazil, Australia and the US. They have been used for submerged stability berms, groins, sill structures for controlling thalweg erosion, scour protection around piers, contraction dikes, dredge material containment and disposal of clean and contaminated materials. Dewatering applications for fine soil from navigation dredged material maintenance projects and sludge lagoons have been limited. Table 1 shows a list of existing and potential applications of this new and innovative technology.

TABLE 1. POTENTIAL GEOBAG, GEOTUBE AND GEOCONTAINER APPLICATIONS

1. DEWATERING APPLICATIONS

- Fine grained dredged material
  - Clean material
  - Contaminated material
- Municipal sewage sludge
  - Sewage sludge lagoon
  - Digester sludge
- Water treatment plants
  - Lime waste
  - Aluminum sulfate waste
- Animal waste lagoons
  - Pork farms
  - Dairy farms
  - Chicken farms
  - Cattle farms
- Paper mills
  - Waste water lagoons
  - Water filtration
- Fly Ash
  - Coal power plants (Wet and dry)
  - Municipal waste (Wet and dry)
  - Paper mills
  - Lumber mills
- Potash lagoons
- Phosphate lagoons
- Radon contaminated Sheetrock waste
- Drilling mud and cuttings (Oil and gas wells)
  - Onshore
  - Offshore
- Mine tailings
  - Oil shale
  - Iron ore
  - Copper
  - Silver
  - Gold

2. DRAINAGE RUNOFF APPLICATIONS

- Airfields
- Automobile parking areas
  - Supermarkets
  - Shopping centers
- Highways
- Residential areas
- Farming operations
- Industrial areas
- Mining operations
- Oil Spills

3. STRUCTURAL APPLICATIONS

<u>Dikes</u>

- Flood protection dikes
  - Permanent structures
  - Temporary structures (FEMA)
- Containment dikes
- Sub-division dikes
- Spur dikes
- Underwater control dikes
  - Contraction dikes
  - Salt water wedge control
  - Thalweg control dikes
  - Bendway weirs
- Mud flat dikes
- Hurricane protection dikes
- Dike breach repair

<u>Coastal</u>

- Groins
- Off shore wave breakwaters

- Beach nourishment
- Shoreline structures
- On shore and off stability shore berms
- Coastal sand dune protection

<u>Rivers</u>

- Thalweg sill structures
- Contraction dikes
- Shoreline structures
- Temporary and permanent flood protection dikes

<u>Wetlands</u>

- Containment islands
- Wetland construction
- Wetlands protection
- Wildlife habitat
  - Oyster reefs
  - Fishing reefs

<u>General Use Categories</u>

- Stability berms
- Erosion control
- Water outfall protection
- Weirs
- Gully repair
- Desert sand dune protection
- Silt fence
- Rock slide protective structures, Snow drifts and avalanche protective structures
- Noise abatement structures
- Walls
- Barricades
  - Domestic
  - Military applications (Explosives, equipment and personnel protection)
- Roadways (Encapsulated soil)
- Surcharge for dewatering applications
- Ballast Applications for Pipelines
  - River crossings
  - Soft soils
  - Frozen soils (perma-frost)

4. EROSION AND SCOUR PROTECTION APPLICATIONS

- Bridge piers and piling
- Tunnels
- Pipeline crossings
- Utility cable crossings
- Walls
- Abutments
- Foundations
- Wharf supports
- Offshore drill rig supports
- Rock groins and jetties
- Wind erosion

5. CONTAINMENT OF CONTAMINATED MATERIALS

- Containment of fine grained dredged material
  - Navigation channels
  - Ship and marina docking areas

Lakes
Golf course ponds
Containment and placement of contaminated dredged materials
Continental shelf
Abyssal planes
Capping contaminated materials

Hazardous and toxic wastes (PCB's, PAH's, heavy metals, pesticides, etc)
Industrial and Paper mill waste
Sewage sludge

Geotextile containers filled with dredged material offer the advantage of ease of placement and construct-ability, cost effectiveness, minimal impact on the environment, and confidence in containment. In addition to filling with sandy materials, geotextile containers filled with fine grained maintenance dredged material provide the opportunity for beneficial use, storage, and subsequent consolidation of this material in dike construction and wetland construction. It has been demonstrated that these geotextile containers retain about 100 percent of the fine grained maintenance dredged material, therefore retaining the contaminants.

During the past 15 to 20 years, various types of containers have been used. Geotextile tubes such as, Geotubes and GeoContainers, which have been copyrighted by Nicolon Corporation, were hydraulically filled with fine-grained sand and have been extensively used on the northern shores of the Netherlands for barrier dikes.

On a project at Leybucht, on the North Sea in Germany during 1988, geotextile tubes were successfully filled with a hydraulic suction dredge for dike construction. The continuous tubes provided temporary protection from waves and currents until fill was placed behind the structure and more permanent wave armor protection was constructed.

Dredged material filled tubes have been used as containment dikes in Brazil and France (Bogossian and others 1982, Perrier 1986, and more recently in the Netherlands and Germany for river "training" structures on the Waal and Old Meuse Rivers and as shoreline protection at Leybucht on the North Sea.

Experimentation with dredged material filled fabric tubes was first tried in Brazil in the early 1980's with a variety of fill material types such as clay balls, shells, and fine grained sand for land reclamation for housing. This technique was also used in France to isolate and contain runoff from a contaminated area.

Geotextile containers were used for dewatering sewage sludge in Germany in the 1980's by lining large elevated cylindrical steel tanks with woven and non-woven geotextiles. Once the sewage sludge stops draining, the geotextile containers and dewatered sludge were allowed to drop out the bottom of the tanks into dump trucks and were hauled to an approved landfill.

The Waterways Experiment Station, US Army Corps of Engineers, Vicksburg, MS (WES) demonstrated in 1992 that geotextile tubes 15 ft wide and 500 ft long and 5 ft high could be filled with fine-grained, dredged material for potential use by the Corps of Engineers for dike construction and wetland creation at Gaillard Island Dredged Material Disposal Island, Mobile, AL. Vegetation growth through containers is very promising. Natural propagation takes place after the tubes are filled and the fined grained dredged material consolidates. The dredged material, at a bulk wet density of 1.3 gr/cc in the geotubes consolidated from an original height of 48 inches to 15 inches in about two months for a reduction of about 70 percent.

Geotextile containers, which are dumped either from dump trucks or split hull, bottom dump hopper barges; have been successfully used to construct underwater stability berms, closures for repair of breached dike, groins, and thalweg scour protection. These containers have been hydraulically and mechanically filled inside split hull, bottom dump hopper barges, moored in place, and dumped. Design concepts for material tensile strength, seaming requirements, and properties with regard to creep, abrasion, ultraviolet protection, tear, and puncture are presently being documented under the Construction Productivity Advancement Research (CPAR) program at the Waterways Experiment Station, Vicksburg, MS.

2.1 Contraction Dikes at Red Eye Crossing, Baton Rouge, MS.

Over 38,000 three cubic yard bags were filled with clean river sand to construct 30 ft high underwater contraction dikes on the Mississippi River for control of siltation and reduction of dredging cost. Five hundred and fifty-six large geocontainers filled with 200 to 550 cubic yards of river sand were also used to construct these contraction dikes. A total of six dikes 600 to 1700 ft long totaling 7000 linear ft were constructed. Construction dredging costs have been reduced from $5 million to less than $1 million per year, virtually paying for the cost of the contraction dikes.

2.2 Disposal of Contaminated Dredged Material, Marina Del Rey, Los Angeles, CA

Approximately 55,000 cy of contaminated maintenance dredged material was successfully contained in forty-four geotextile containers and placed with split hull, bottom dump barges in a shallow water habitat and capped with a 12 ft thick layer of clean sandy dredged material. The Marina Del Rey dredged materials contained about 7 to 8 percent fine grained soil and was contaminated with lead, zinc and copper. These materials were mechanically dredged with a clamshell bucket and placed in geotextile containers. The containers were sewn closed and placed within the Port of Los Angeles Shallow Water Habitat Confined Aquatic Disposal site.

The Marina Del Rey dredged materials were contaminated with a number of heavy metals, polychlorinated biphenyls (PCB), polynuclear aromatic hydrocarbons (PAH's), Phthalates, organnotins, and conventionals such as oil and grease, hydrocarbons, sulfides and ammonia. The only contaminates that were above acceptable levels were copper (CU), lead (PB), and zinc (ZN). Percent total solid tests and chemical tests were conducted on water and dredged material sediment that passed through the non-woven polyester fabric. The percent concentration of solids remaining after evaporation of the water and sediment that passed through the non-woven fabric ranged from about 2.57 to 3.70 percent

(Total Solids). The percent concentration of solids in seawater varies from about 2.5 to 3.0 percent (Total Solids); therefore the excess ranged from about 0.07 to 0.70 percent (Total Solids).

A summary of the test results and the water quality criteria established by the Regional Water Quality Control Board (RWQCB) are shown as follows:

Dilution Requirements for Contaminants of Concern and Concentrations Measured from Water and Sediment Passing Geotextile Filter Fabric			
Chemical of Concern	Chemical Concentration Sediment Sample mg/kg (ppm)	Total* Solids Concentration mg/kg (ppm)	RWQCB Water Quality Criteria mg/kg (ppm)
Copper (CU)	138	5.0	30
Lead (PB)	400	1.3	20
Zinc (ZN)	380	10.0	200

* Concentration Measured Passing Geotextile Before Dilution

2.3 Dewatering Contaminated Dredged Material, Port of Oakland, Oakland, CA

During the Marina Del Rey project, the Port of Oakland, CA, was involved in mechanically excavating contaminated maintenance dredged material into a holding barge and then hydraulically pumping it into geotextile tubes for dewatering and subsequent landfill disposal. Geotextile tubes were successfully filled on Pier #10 to a height of about 5 to 8 ft with contaminated dredged material and allowed to drain and consolidate to about 40 percent of their original volume prior to subsequent landfill placement. The water, filtered through a 16 ounce non-woven filter fabric, met the requirement for discharge into navigable waters.

The weight loss from dewatering by gravitational forces, wind and desiccation drying has proven to be construction-practical and economically feasible alternative to hauling these soft saturated materials directly to a landfill.

2.4 Contaminated Dredged Material, Miami River, Miami, FL.

Over 160 contaminated dredged material samples were tested from Miami River, and extensive laboratory tests were conducted using polyester geotextile geocontainers filled with this material. Amphipods exposed to the effluent water that passed through the geotextile fabrics were not harmed. Over one million cubic yards of dredged material is planned to be dredged from the Miami River, placed in GeoContainers and the containers subsequently placed in an approved dredged material disposal site about three miles off shore in 600 ft of water and capped with clean sand.

2.5 Dewatering Fly Ash.

Dr. T.D. Stark, University of Illinois, Geotechnical Department, Civil Engineering, is presently conducting a research study to determine the proper design and construction techniques for filling and dewatering coal fly ash from the Dallman Power Plant at Springfield, IL. Geotubes filled with fly ash will be used to construct cross dikes and to raise the perimeter dikes for additional storage capacity of a 34 acre confined disposal facility. Dewatered fly ash will also be sold for beneficial use in roadway construction and dike fill material.

2.6. Hog and Dairy Farm Waste Lagoons.

Dr. Stark is also involved in research to determine improved dewatering techniques for hog and dairy sewage lagoon sediments using Geotubes specifically designed and engineered to improve the storage capacity of the lagoons. The pork and dairy farm industries have considerable interest in the outcome of this research effort at the University of Illinois.

2.6 Aluminum Sulfate and Lime Waste Lagoons.

Aluminum sulfate and lime wastes have also been successfully removed from sludge lagoons located in Vicksburg, MS, and Baton Rouge, LA, through the use of geotextile tubes. The percent solids passing through the geotextile containers were less than 10 mg/liter. Full scale research tests for dewatering calcareous lime and aluminum sulfate brine sludge are presently being conducted by George Guttner and Thad Foreman, Integrated Technical Service, Inc. in Baton Rouge, LA. Preliminary tests results indicate that this dewatering technique is construction- practical and economically feasible when compared with other conventional alternatives for dewatering these material types.

3. SEWAGE SLUDGE DEWATERING TESTS, CITY OF VICKSBURG WATER POLLUTION CONTROL CENTER, VICKSBURG, MS

3.1. Introduction

The Nicolon Corporation provided, at no cost, two geotextile bags and one Geotube to the City of Vicksburg Water Pollution Control Center, Vicksburg, MS, for the purpose of determining the filtration and consolidation characteristics of a large geotextile Geotube filled with sewage sludge.

It was shown in August 1995 through placement of lime and aluminum sulphate wastes from the Eagle Lake and Culkin Water Districts Vicksburg, MS, disposal lagoons that the geotextile bags were capable of retaining almost 100 percent of the fine materials. The Vicksburg Water Treatment Plant was dumping a waste stream of lime north of the Vicksburg Harbor Project in the Long Lake area. In July 1995, the Ergon Corporation collapsed the Vicksburg Water Treatment Plant's south discharge pipe that dumped lime into the Yazoo River. Therefore, dumping north of the Harbor Project was the only discharge alternative.

Geotec Associates proposed to the City of Vicksburg Engineering Department that they consider the use of geotextile tubes to dewater and consolidate these materials rather than dump them into the road ditch north of the Harbor Project. The Vicksburg Engineering Department suggested that since they were too far along with their decision to construct a belt press plant at the Water Treatment Plant, that GEOTEC should contact Rose Mary Bagby, Manager of the Vicksburg Waste Water Treatment Plant.

GEOTEC Associates also proposed to the Culkin Water District Board that aluminum sulfate from their disposal lagoon could be dewatered with the geotextile tubes. Filtration bag tests performed at the Culkin Water District plant demonstrated that the geotextile fabric bags could retain 100 percent of these materials. After a presentation and demonstration of this concept, the Culkin Water District declined its use. They have presently contracted a Jackson Engineering firm to investigate and survey other alternative methods to dewater and dispose of aluminum sulfate lagoon materials. A solution to these dewatering and consolidation problems, developed by the Waterways Experiment Station, Vicksburg, MS, is currently available.

The US Environmental Regulatory Agency has required wastewater managers, under 40 CFR, Part 503 Regulation and Specific Guidelines, to find other alternatives for dewatering and disposal of sewage sludge. Preferably these alternatives would be beneficial, such as combining green waste, fly ash, kiln dust, and/or lime waste and dewatered sewage sludge for land applications. The present method of disposal and the method that has been used for the past 23 years by the Vicksburg Water Pollution Control Center has been disposing digester sludge into two lagoons that occupy about 4.5 acres. They have been directed to discontinue the use of these lagoons and submit alternative methods of disposal for consideration and approval.

3.2 Geotextile Fabric Properties.

3.2.1 Outer Bag Liner. The outer geotextile container for both bags consisted of a high strength woven polyester fabric that was specifically designed for use in the fabrication of geotextile tubes and containers. These tensile tests were conducted using ASTM D4595 and ASTM D4884 wide width tests for the warp and weft seam strength tests, respectively. The fabric had a ultimate wide width tensile strength of 1245 pounds per inch wide width (pli) in the warp and 1300 pli in the weft (cross machine direction); and the maximum strain was 13.1 and 13.6 percent in the warp (warp machine direction) and weft, respectively. The fabric exceeded the specified 1000 pli at 10 percent strain in both the warp and weft directions for the fabric specification. The fabric exhibited 1065 pli in the warp and 1075 pli in the weft at 10 percent strain. The apparent opening size (AOS)for the woven fabric is a US Standard sieve number 60 when dry and about when100 saturated.

3.2.2 Bag Inner Liner. The inner geotextile container liner consisted of a 16 oz/sy non-woven polyester and polypropylene geotextile fabrics for the two bags respectively. The polyester inner liner has an average thickness of 200 mil and the polyethylene fabric has an average thickness of 185 mils. The average grab tensile strength for the polyester was 375 pli and 350 pli for the polypropylene. The purpose of the non-woven fabric was retention of the fine sludge material. The AOS for the both the polyester and polypropylene non-woven fabrics was a US Standard sieve number 100.

3.2.3 Bag Seam Strength. Wide width seam tests indicated that "J" seam strength for both the polyester warp and weft directions exceeded 450 pli. The woven polypropylene fabric seams for the Geotube was about 250 pli in the warp and weft. All seams were "J" seams. Seams consisted of type 401, double lock stitches that were sewn with a double needle, Union Special, Model #80200 sewing machine. This machine is capable of sewing two parallel seams about a quarter inch apart. The thread was 2 ply, 1000 denier passing through the needles and 9 ply, 1000 denier passing through the looper.

3.3 Geotextile Bags Tests.

Sewage sludge from the primary digester was used to fill two bags for the purpose of evaluating the dewatering and consolidation capabilities and effluent water quality for design and filling a large Geotube. A proposed ASTM test method was used to determine the flow rate of suspended solids from the geotextile containment system using two different non-woven, inner liner fabric systems in each bag.

Prior to filling the large 15-ft wide, 30 ft long and 5 ft high geotube, municipal sewage sludge was placed in two geotextile bags for the purpose of evaluating the dewatering and filtration capabilities of a 16 oz/sy polyester and a 16 oz/sy polypropylene non-woven fabric. The non-woven fabrics served as the inner filtration liner for a woven polyester outer liner. The bag was 48 inches in circumference and about 65 inches long and contained about 48 gallons of sludge. The purpose of these tests was to determine the efficiency of the two types of inner and outer liner systems.

4. RESULTS OF BAG 1 SLUDGE DATA

The bags were attached in a wooden frame so that they hung over an aluminum catch pan to retain the effluent water that passed through the fabric. Sewage sludge was pumped out of the digester into 5 gallon buckets and then poured into the bag (See Figure No. 1). Approximately 48 gallons of sewage sludge were placed in each bag and allowed to drain. Effluent water samples from the catch pan and sewage sludge samples taken from the 5 gallon buckets were obtained for testing percent solids, total suspended solids, volatiles, heavy metals and coliforms (See Figure No. 2).

4.1 Consolidation. The sludge placed in Bag 1 (16 oz non-woven polyester liner) was 6.6 percent solids during filling on 18 October 1995. Using this calculated percent solids, the measured initial moisture content was 1415 percent, the initial void ratio was 35.4, and the initial wet unit weight density was 1.04 gr./cc. Bag 1 was filled to an initial depth of about 62 inches and surface readings of the sludge inside the bag were measured and recorded from the top of the wooden frame as the sludge began to dewater from desiccation and consolidation. The height of the sludge in the bag is plotted versus time in Figure No. 3. There was very little change in the 48 inch bag circumference after consolidation. Consolidation was fairly linear and rapid in the first 5 days and exponential after the first week. It took about 14 minutes to fill the bag with 48 gallons of sludge.

The final surface reading was 47 inches on 27 February 1996. About 15 inches of consolidated sludge remained in the bottom of the bag after 132 days. Figure No. 4 shows the dimensions of Bags 1 and 2, height of the sludge, and sludge properties during filling and after consolidation. Ninety percent of the consolidation took place in the first 5 days. This reduction was about 75 percent of the initial sludge height of 62 inches. The percent solids were calculated to be 31 percent, void ratio 5.7, moisture content 226 percent, and the bulk wet density was 1.22 gr/cc.

4.2 Total Suspended Solids. The material pumped in Bag 1 at 6.6 percent solids had a Total Suspended Solids content of 69,350 mg/l. The 100 gm sample that had 6.6 percent solids content was 27.3 percent volatile and the remainder was an inorganic silt and clay. The temperature of the sludge was 96 degrees Fahrenheit. Total Suspended Solids were measured with an analytical balance using Gelman AE glass fiber filters dried at 103 degrees F. Data collected for Bag 1, are plotted in Figure No. 5 and tabulated in the following:

Bag 1, Non-woven polyester inner liner and woven polyester outer liner	
Time After Filling Minutes	Total Suspended Solids mg/liter
1	302
2	250
6	76
11	26
23	28
36	18
41	18
49	24
60	14
65	12
351	7
471	7

The total percent solids permitted for discharge by the EPA and The Mississippi Department of Environmental Quality is 30 mg/liter. This requirement was met in less than 11 minutes under these conditions.

4.3 Fecal Coliform. The results of the Fecal Coliform Bacterial count performed by the Membrane Filter Technique and BOD5 analyses were as follows:

Bag 1, Non-woven polyester inner liner and woven polyester outer liner	
Time Collected Minutes	Colonies per 100 ml
1	204,000
6	137,000
11	102,000
41	49,000
48	59,000
65	27,000

The fecal coliform level was class A or 100,000 colonies per 100 ml at about 11 minutes.

5. RESULTS BAG 2 SLUDGE DATA

5.1 Bag 2. Sludge placed in Bag 2 (16 oz/sy non-woven polypropylene inner liner) was 14.9 percent solids during filling on 24 October 1995. Using this measured percent solids, the calculated initial moisture content was 571 percent, the initial void ratio was 22.8, and the initial wet density was 1.06 gr./cc. The bag was filled to an initial depth or height of about 61 inches and surface readings of the sludge inside the bag were measured and recorded from the top of the wooden frame as the sludge dewatered. There was very little change in the bag circumference during or after consolidation. Consolidation was fairly linear and rapid in the first 4 days and exponential after the first week as can be seen in Figure No. 3.

The final surface reading was 41.5 inches in Bag 2 on 27 February 1996. About 19.5 inches of consolidated sludge remained in the bottom of Bag 2 after 132 days. Figure No. 4 shows the dimensions of Bag 2, height of the sludge, and sludge properties during filling and consolidation. Ninety percent of the consolidation took place in the first 4 days. This reduction was about 53 percent of the initial sludge height of 61 inches. The percent solids were calculated to be 33 percent, void ratio 5.1, moisture content 204 percent, and the bulk wet density was 1.25 gr./cc. It took about 13 minutes to fill the bag with 48 gallons of sludge.

5.2 Total Suspended Solids. The material pumped into Bag 2 at 14.9 percent solids had a Total Suspended Solids content of 234,350 mg/l. The 100 gm sample that had 14.9 percent solids content was 18.79 percent volatile and the remainder was an inorganic silt and clay. The temperature of the sludge was 96 degrees Fahrenheit. Total Suspended Solids were measured with an analytical balance using Gelman AE glass fiber filters dried at 103 degrees F. Total Suspended Solids data collected during drainage through the geotextile fabric bag is plotted in Figure No. 5 and tabulated in the following:

Bag 2, Non-woven polypropylene inner liner and woven polyester outer liner	
Time After Filling Minutes	Total Suspended Solids mg/liter
1	940
9	456
16	238
27	188
29	134
34	110
37	96
39	84
47	108
59	58
77	29
82	29
119	18
139	19

The total percent solids permitted by the EPA was 30 mg/liter and this was reached in less than 77 minutes.

5.3 Fecal Coliform. The results of the Fecal Coliform Bacterial count performed by the Membrane Filter Technique and BOD5 analyses are shown tabulated below for the effluent water passing through Bag 2:

Time Collected Minutes	Colonies per 100 ml
1	52,000
16	115,000

29	92,000
37	85,000
47	72,000
77	43,000
82	34,000

The fecal coliform level of 100,000 colonies per 100 ml or class A was reached in less than 29 minutes.

6. RESULTS AND ANALYSIS

There was not much control over the percent solids for filling the bag on any given day from the sludge digester. However, there did not appear to be much difference in the time of dewatering or consolidation of the lower or higher percent solids content materials in the bags. The higher moisture content sludge material took about 5 days and the lower moisture content materials took about 4 days to achieve about 90 percent consolidation in the bags. There also did not appear to be a significant difference in the dewatering capabilities of the polyester versus the polypropylene inner liner, non-woven fabrics. The percent solids, moisture content and wet density approached approximately the same values in about the same amount of time regardless of the initial sludge properties. This is illustrated by comparison of the test results from each bag shown in Figure No. 4. Data shown in Figure No.4 was calculated based on the percent solids measured and volume of sludge for a given height in the bags. All calculations were based on an assumed Specific Gravity of 2.5.

For comparison purpose, Figure No. 6 shows theoretical curves for void ratio, percent solids, and saturated density versus moisture content for saturated soils, including equations for each curve (Typical maintenance dredged materials, Specific Gravity = 2.7). These same equations and theory are applicable to all sludge types.

The Total Suspended Solids (TSS) were about three times lower for the non-woven polyester inner liner than for the non-woven polypropylene fabric during the initial drainage or flush of water and fine soil through the fabric. After a soil filter cake build up on the fabric, the TSS for both bags stabilized. The TSS was less than 30 mg/l in about 11 minutes for Bag 1 (non-woven polyester liner) and about one hour for Bag 2 (non-woven polyester liner). These tests are non-conclusive and it is recommended that a number of tests be conducted under a more controlled environment because these materials may not be representatives for all sludge.

6.1 Heavy Metal Tests. Heavy metal content tests were conducted on the effluent water passing through the inner liner and outer fabrics for Bag 1 (polyester non-woven inner liner) and Bag 2 (polypropylene non-woven inner liner). The results of these tests are shown below:

DIGESTER #1 - LIQUIDS FROM GEOTEXTILE TUBES

Parameter/ Method # Total Metals	Unfiltered Sludge		Sample #1 Bag 1	Sample #2 Bag 2	Method Detection Limit MDL
	May 95	Dec 95			
Arsenic/7060	1.52	1.4	0.008	ND	0.005
Chromium/7190	1.9	4.8	ND	ND	0.04
Nickel/6010	5.8	3.2	0.13	ND	0.01

The data is reported in mg/kg and the analyses were performed in accordance with 40 CFR 136 and amendments (Bonner Analytical Testing Company, Hattiesburg, MS).

7. GEOTEXTILE GEOTUBE TESTS

7.1 Introduction

The Nicolon Corporation provided at no cost a geotube for this research project. The geotube consisted of a 16-oz, non-woven polypropylene inner liner and a woven polypropylene outer liner for support. The geotube was 15 ft wide and 30 ft long.

7.2 Geotextile Fabric Properties

7.2.1 Geotube. The outer bag consisted of Nicolon Geolon GT 500, which is a woven polypropylene fabric. This fabric was initially used in construction of geotubes. Contractors had a problems with failure of these fabrics because they could not or would not, monitor the pressure at geotube inlets during filling. Another problem with woven polypropylene fabric is that they have tendency to fail due to creep failure under high, sustained loads. Nicolon uses polyester fabrics in all geotube designs unless otherwise specified. The woven polypropylene fabric had an ultimate wide width, tensile strength of 400 pli in the warp and 400 pli in the weft. The tests were conducted using ASTM D4595 and ASTM D4884. The maximum strain was 20 percent in the warp and weft, respectively. The apparent opening size (AOS) for the woven fabric is a US Standard sieve number 40-70.

7.2.2 Inner Geotube liner. The inner geotube liner consisted of a 16 oz/sy non-woven polypropylene geotextile fabric. The polypropylene inner liner has an average thickness of 185 mils. The average grab tensile strength for the polypropylene was 350 pli. The purpose of the non-woven fabric was retention of the fine sludge material. The AOS for the polypropylene non-woven fabric was a US Standard sieve number 100.

7.2.3 Geotube Seam Strength. The woven polypropylene fabric seam strength was about 250 pli in the warp and weft. All seams were "J" seams. Seams consisted of type 401, double lock stitch that was sewn with a double needle, Union Special Model #80200, sewing machine. The machine is capable of sewing two parallel seams about one quarter inch apart. The thread was a 2 ply 1000 denier passing through the needles and 9 ply 1000 denier passing through the looper.

7.3 Filling the Geotube.

A 2 x 6 inch wooden frame was constructed to form a box 16 ft wide and 32 ft long. The box was lined with a 4-mil thick visqueen liner to contain the effluent water from the geotube. Figure No. 7 shows the geotube, wooden frame box and visqueen liner prior to filling.

While pumping the digester to the lagoon on 28 November 1995 an attempt was made to fill the geotube with a one and one half inch diameter cloth fire hose connected to the sample line. This attempt failed because of low flow. The idea was not very successful because the digester was pumped too low before the geotube was filled. Only about 3 to 4 inches of sludge height was achieved.

The second attempt, 7 December 1995, to fill the geotube was with the suction hose of a 4-inch diameter pump located in the sewage lagoon. However, this idea was not successful because the suction line was too long; and when it was shortened, the sewage density was too low. The pump was only able to pick up and pump the decant water off of the top the heavy sludge in the lagoon. Only about 5 to 6 inches of sludge height was achieved.

The third attempt, 26 January 1996, to fill the geotube was successful. The fire hose was attached directly to the drain line ahead of the digester pump and allowed to gravity flow directly into the geotube. The elevation of the bottom of the digester was about 5 to 6 ft higher than the proposed 5 ft height of the geotube. Figure No.8 shows the geotextile tube being filled to a height of about 60 inches with sewage sludge. Figure No.9 shows the geotube after it consolidated to a height of about 48 inches in 5 days. Figure No.10 shows the geotube at a height of 21 inches after 26 days of consolidation.

Once the geotube was filled to the desired height, periodic samples of the sludge from the geotube were obtained and geotube height measurements were recorded. About 11 days after filling the geotube an ice storm caused a build-up of 2 inches of ice on the geotube for about two days. The weight of ice for these two days caused an increase, in the rate of consolidation (Figure No. 12). This slight increase in weight caused the sludge to consolidate slightly more than it would have under its own weight.

7.4 Geotube Data Analysis.

The required pressure, 0.3 psi, to fill the geotube to a height of 5 ft was determined using a computer program, GEOCOPS. A plot showing the required pump pressure, tube height, cross-sectional area and fabric tensile strength for the geotube during various stages of consolidation is shown in Figure No. 11. The geotube consolidated 90 percent of its initial height, or area, in the first 26 days after filling. Using geotechnical consolidation theory and beginning with an initial measured percent solids, the density, percent solids, void ratio, and wet bulk density, can be calculated for changes in the cross-sectional area. These calculations and measured values from sludge samples taken from the geotube are shown tabulated below and plotted in Figure 12.

Self Weight Consolidation of
Sewage Sludge Calculated Based on Changes in Geotube Geometry
(See Figure No. 11)

Days Consoli- dated	Geotube Height, inches	Geotube End Area, square feet	Geotube Incre- mental Change, square feet	Void Ratio Change)e	Void Ratio e	Water Content %	Percent Solids %	Wet Bulk Specific Gravity **gr./ml
0	60	53	0	0	31.05	1150	8.0*	1.047
4	50	46	7	4.23	26.82	1073	8.5	1.052
10	32	33	20	12.09	19.0	758	11.5	1.075
26	21	24	29	17.54	13.51	541	15.6	1.10
53	17.5	20	33	20.0	11.05	409	19.6	1.12

* Initial percent solids = 8.0 %
** Assumed Specific Gravity of Solids Gs = 2.5
Measured Wet Bulk Specific Gravity at 22 days = 1.12 gr./cc and percent solids = 17.1%
Measured Wet Bulk Specific Gravity at 32 days = 1.13 gr./cc and percent solids = 19.2%
Measured Wet Bulk Specific Gravity at 65 days = 1.27 gr./cc and percent solids = 21.4%

The calculated percent solids based on the initial measured value and the geotube geometry are slightly

lower than the measured percent solids. This increase in density and percent solids is probably due to the three-dimensional drainage and consolidation of the short 30 ft long geotube.
Volume loss and flow rates during the primary self-weight consolidation of the sewage sludge in the 15 ft wide, 30 ft long geotube is shown tabulated in the following table.

Volume Loss and Flow Rates
During Primary Self Weight Consolidation of Sewage Sludge

Days Consoli-dated	Geotube Height, ft	Geotube Area, ft^2	Geotube Volume cy/ft	Geotube Volume gal/ft	Total Volume Loss gal/ft	*Loss Rate gal/ft-day	Assumed 100 ft Geotube gal/ft-day
0	5.0	53	2.0	400	0	0	0
4	4.2	46	1.7	344	56	14.0	1400
10	2.7	33	1.22	247	153	15.3	1530
12	2.2	28	1.04	210	190	15.8	1580

*Average loss = 15 gal/ft-day

During the first 12 days of primary consolidation the average loss rate was about 15 gallon per foot-day. The average loss rate for an assumed 100 ft long geotube is about 1500 gallon per foot-day. It is assumed that these loss rates may decrease as the geotube accumulates solids during consolidation.

8. Results of the Geobags and Geotube Analysis

The geotube held about 2 cy/ft for a 15-ft wide tube or approximately 12,000 gallons, whereas a 48-inch circumference bag 5 ft long only held 48 gallons. The geotube held about 404 gallons of sludge per foot; therefore, the results from the bag tests may not be used directly to predict geotube performance.

The initial percent solids in Bags 1 and 2 were 6.6 to 14.9% respectively. The maximum percent solids

increase for Bags and 1 and 2 was 31% and 33%, for 128 and 132 days, respectively.
The geotube had initial percent solids of 8.0% at a height of 60 inches and 21.4% solids at a height of 17.5 inches after 65 days of consolidation. Ninety percent consolidation occurred in the geotube in about 26 days versus 4 to 5 days for the geotextile bags. At 90% consolidation the geotube dropped to a height of 21 inches. The geotube has consolidated from a height of 60 to 16.5 inches on 9 April 1996. Based on past experience it is estimated that the geotube will subside to about 15 inches as a result of self weight consolidation which would be about 27 percent solids or a reduction of about 75 percent of the initial volume.

The average loss rate for the geotube was about 15 gallon per foot-day during the first 12 days of the primary consolidation phase. A 100-ft long geotube would drain about 1500 gallon per foot-day if allowed to gravity drain. Geotubes that are fitted with drainpipes attached to a vacuum pump will consolidate at a much faster rate.

The Total Percent Solids passing through the non-woven polyester geotextile fabrics performed slightly better than the non-polypropylene fabrics. TSS for effluent water passing through the polyester fabric was less than 26 mg/l after 11 minutes of drainage and consolidation time.

The fecal coliform count per 100 ml was less with the polypropylene fabric than for the polyester fabric.

9. CONCLUSIONS AND RECOMMENDATIONS

It was concluded that the geotextile bags and the geotube were capable of retaining the fine grained sewage sludge. These materials responded similarly to the soil characteristics of maintenance dredged material. It was shown that the geotextiles are capable of filtering the sludge so that the effluent water passing through the fabrics will meets the 30 mg/l discharge requirements of EPS in less than 11 minutes of drainage time. It was also concluded that this new and innovative technology is capable of competing economically with other alternative dewatering techniques for sludge. This technique is passive, and does not require extensive or constant labor and maintenance of equipment. This technique is capable of increasing the percent solids to about 22 to 27 percent in relatively short periods of time.

It is recommended that additives such polymers, fly ash, or highly oxidized water etc; be added during or after consolidation in the geotubes to achieve a greater bacterial reduction. One alternative is to do nothing and let the dewatered sludge stabilize naturally in the tube. It is also recommended that small to medium size water and wastewater treatment plants consider the use of this new and innovative technology for dewatering sludge. Transportable geotubes are available for dump trucks and/or trailers after the sludge has dewatered. Vacuum consolidation systems are also available. Current research is ongoing but it is recommended that additional testing be conducted to substantiate this research effort.

10. ACKNOWLEDGMENTS

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Figure No. 1. Geotextile bags hanging in the wooden frame being filled with sewage sludge for filteration testing.

Figure No. 2. Collecting effluent water passing through the geotextile bags and sewage samples for testing.

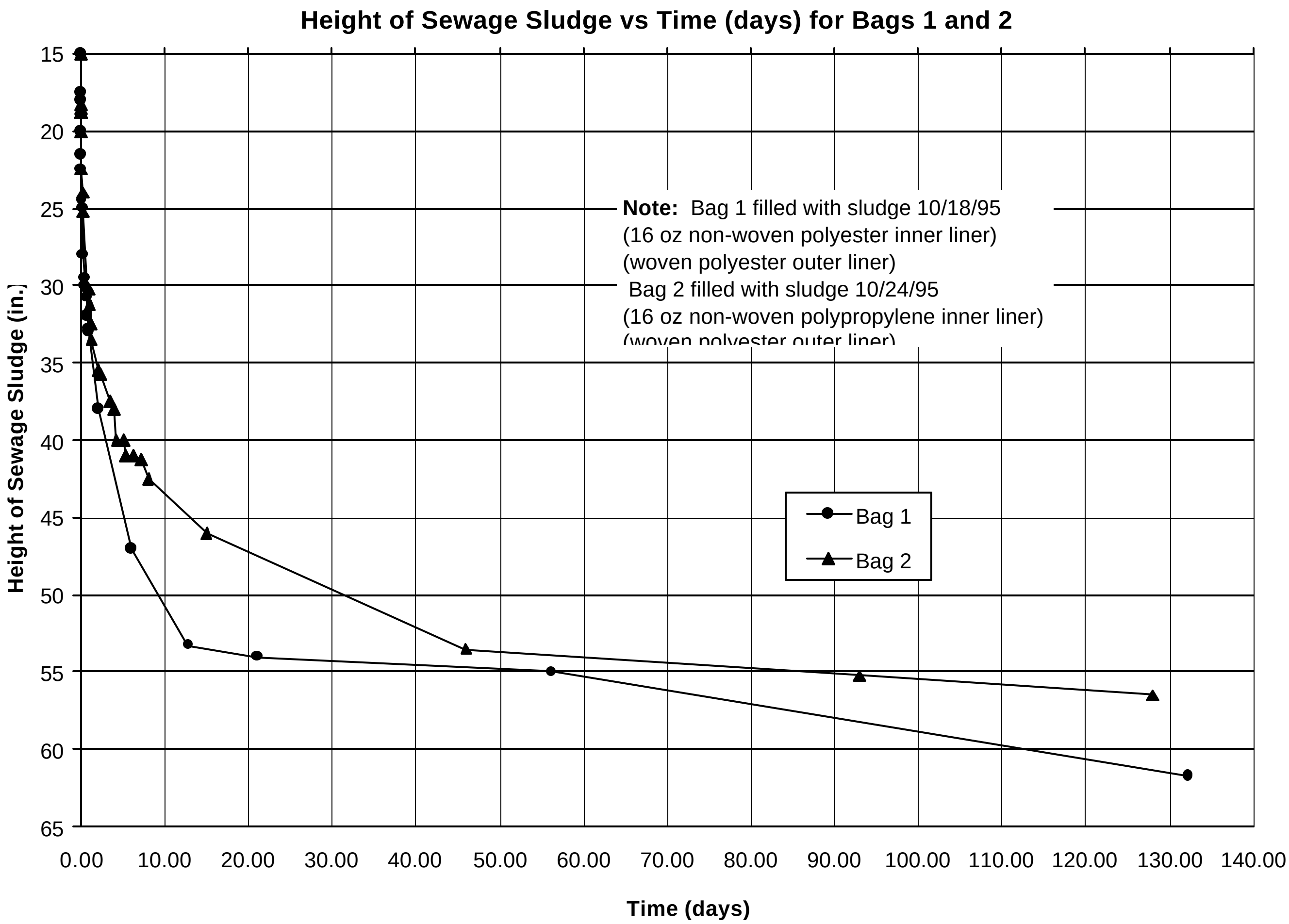
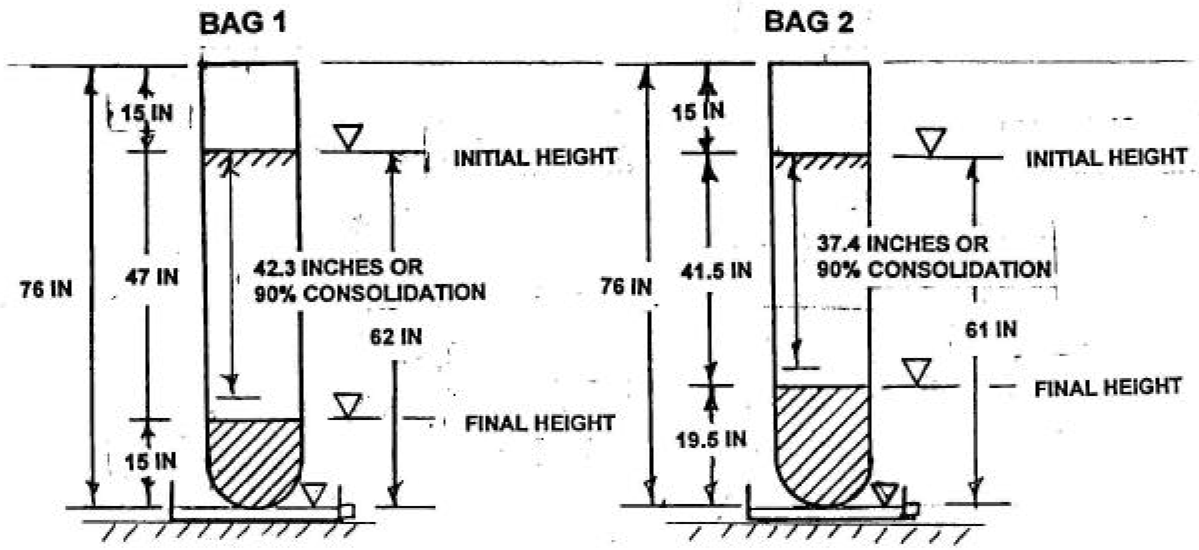


Figure No. 3. Height of sewage sludge during consolidation versus time in days for Bags 1 and 2



SLUDGE PROPERTIES FOR BAG 1 AND 2

Bag No.	Percent Solids Measured	Percent Moisture Content	Void Ratio	Wet Bulk Density gr/cc	Remarks
1	6.6	1415	35.4	1.04	After filling H = 62 inches
2	14.9	571	22.9	1.06	After filling H = 61 inches
1	24.2	314	7.9	1.17	After 5 days or about 90% Consolidation H = 42.3 inches
2	27.7	261	6.6	1.20	After 4 days or about 90% Consolidation H = 37.4 inches
1	31	226	5.7	1.22	After 132 days H = 15.0 inches
2	33	204	5.1	1.25	After 128 days H = 19.5 inches

Figure No. 4. Dimensions of Bag 1 and 2, height of sludge and sludge properties during filling and consolidation.

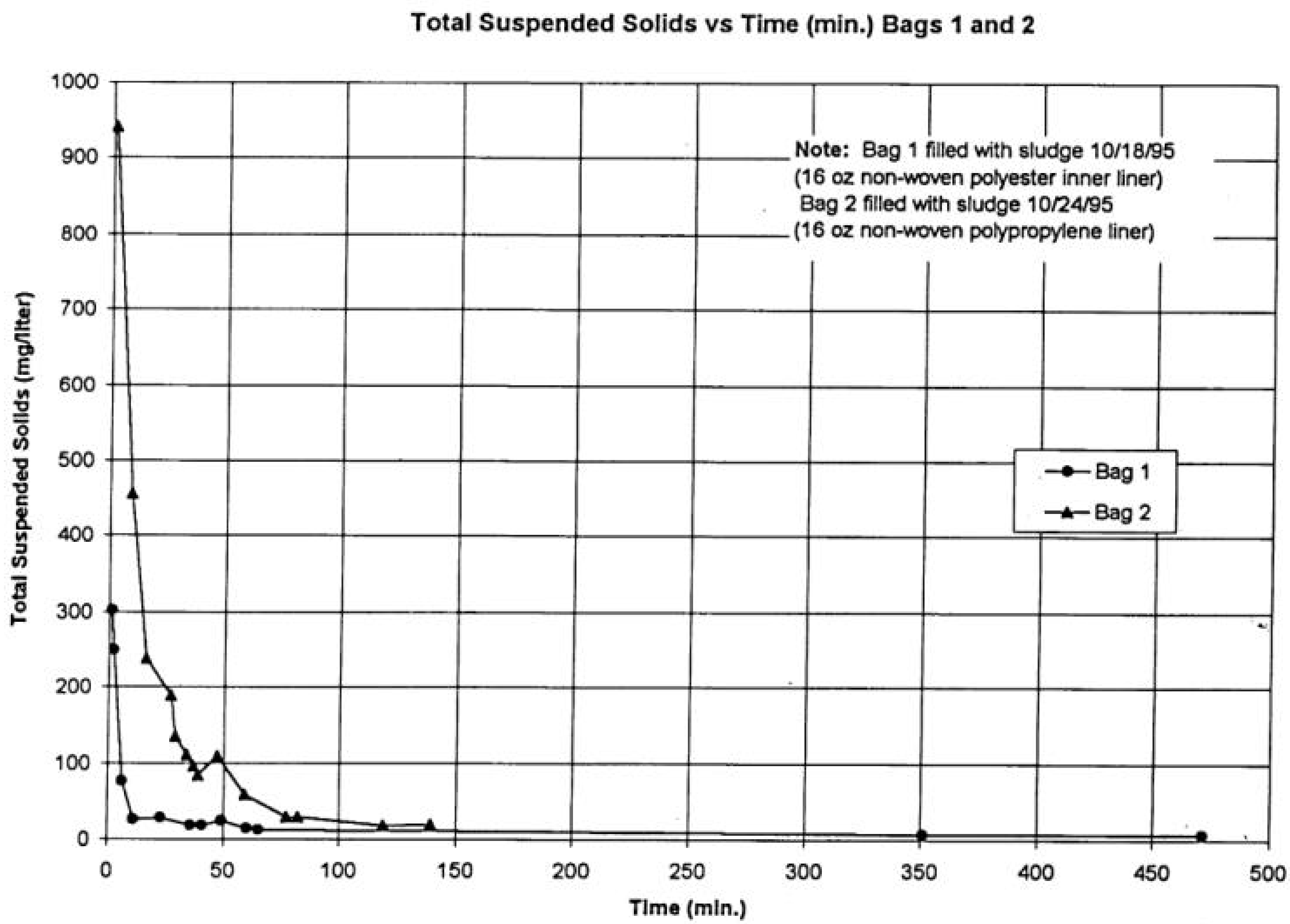


Figure No. 5. Total Suspended Solids versus time in minutes for Bags 1 and 2.

Soil Properties

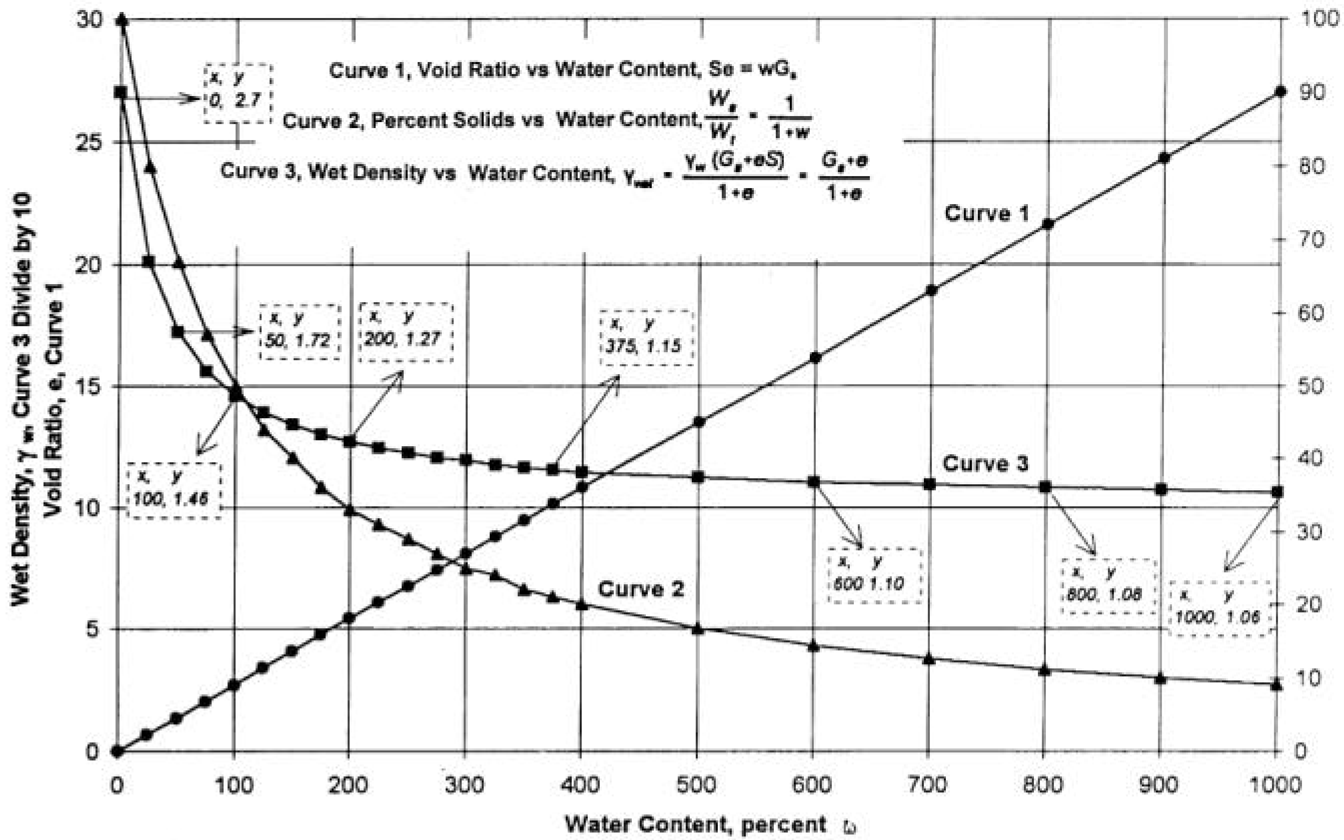


Figure No. 6. Theoretical geotechnical curves for void ratio, percent solids, and saturated density versus moisture content for saturated soils, including equations for each curve.(Specific Gravity = 2.7)

Figure No. 7 Geotextile tube, wooden 2x6 inch frame and Visqueen liner being laid out prior to filling.

Figure No. 8 Geotextile tube being filled to a height of about 60 inches with sewage sludge from digester by gravity flow.

Figure No. 9 Geotextile tube 4 days after filling consolidated to a height of about 50 inches.

Figure No. 10 Geotextile tube 26 days after filling consolidated to a height of about 21 inches.

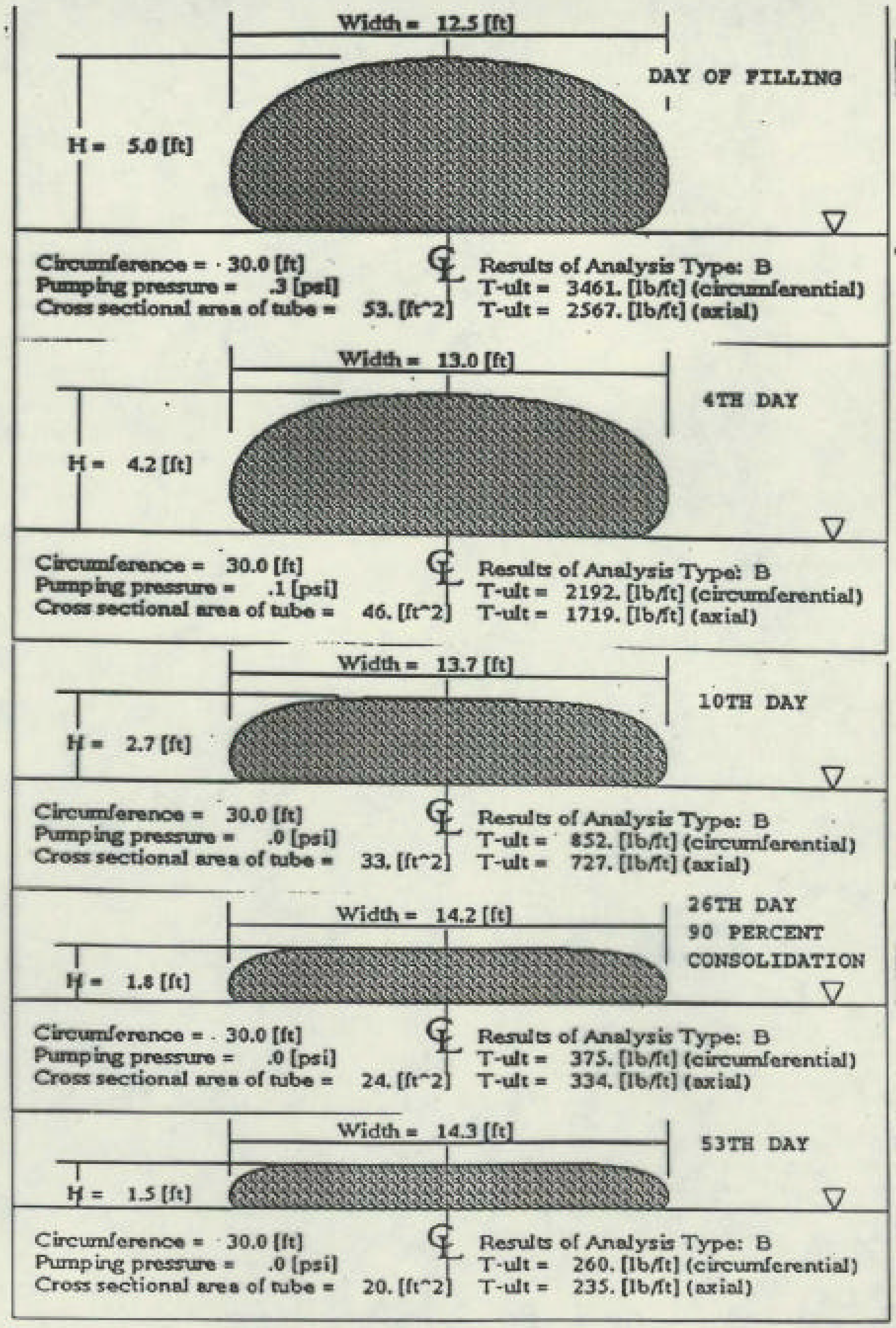


Figure No. 11. GEOCOPS plots showing theoretical geotube shapes, heights, cross-sectional areas, and required fabric tensile strengths and dimensions of the geotube after filling and during consolidation.

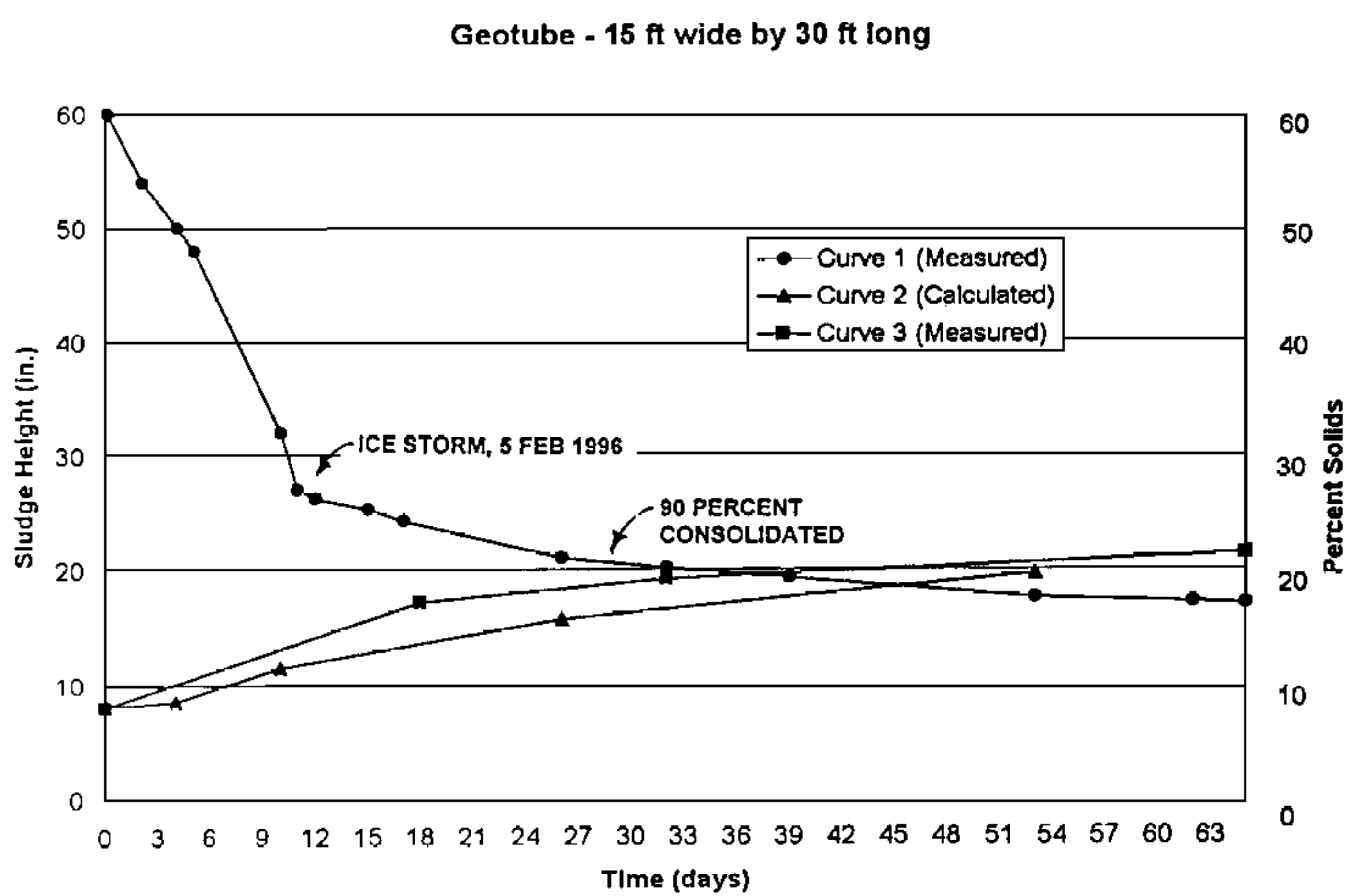


Figure No. 12. Consolidated height and percent solids versus time for the 15 ft wide, 30 ft long, and 5 ft high geotube.