COMMONWEALTH OF PENNSYLVANIA
Department of Transportation

RESEARCH PROJECT NO. 96-054B

GEOSYNTHETIC CLAY LINER

FINAL REPORT
AUGUST 1998

Prepared by:
K. Allen Bowser, P.E.
District 2-0

PENNSYLLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF CONSTRUCTION AND MATERIALS
ENGINEERING TECHNOLOGY & INFORMATION DIVISION

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The alignment of the Milroy bypass (SR0322, Sections B01 & B02) crosses limestone and dolomite formations. Geotechnical investigations during the project design phase identified areas of high potential for sinkhole activity. In July and August, 1997, drainage ditches in the sinkhole prone areas of Section B01 were lined with impermeable geosynthetic clay liners to prevent the infiltration of surface water, a prime cause of sinkhole development. This report evaluates the constructability and performance of this lining method in the prevention of sinkholes within the project drainage system. The study will continue for 18 months after the completion of the installation.

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Conducted by:
PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
Bureau of Construction and Materials
Engineering Technology & Information Division
New Products & Research Section
And
Engineering District 2-0, Geotechnical Unit

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EXECUTIVE SUMMARY

The purpose of this study is to evaluate the performance of geosynthetic clay liners to prevent sinkhole development in the drainage systems of highway construction projects. This report covers the installation of geosynthetic clay liners (GCL) in drainage ditches located in sinkhole-prone areas on a highway construction project in Mifflin County. This project (SR 0322-B01) is the first of two new road sections that will complete a bypass around the town of Milroy in Mifflin County. The alignment of SR 0322-B01 crosses over limestone and dolomite formations that are susceptible to sinkhole development.

Geosynthetic clay liners are routinely used to provide impermeable barriers in sanitary land fills and settlement lagoons. These clay liners are manufactured by placing sodium bentonite between two layers of geotextile that are bonded together. Sodium Bentonite is a naturally occurring clay mineral that swells when wet. When hydrated under the confinement of the geotextile, the bentonite forms a clay layer of low permeability, which gives the equivalent hydraulic protection of several feet of compacted clay. The GCL is delivered to the project in rolls 15 feet (4.72 meters) wide and 150 feet (45.72 meters) long and each roll weighs 2,661 pounds (1207 Kilograms).

Installation of the GCL on SR 0322-B01 began in August 1997 and continues to date on the second road section (SR 0322-B02). These projects will be completed in November 1998. The installation of the GCL is labor intensive, involving an equipment operator and four laborers to cut the GCL to size and move it into place. The GCL must be protected by a cover layer of soil or granular material at least 8 inches think and must not be exposed to moisture prior to placement of the cover layer. The District Geotechnical Engineer visited the GCL sites monthly and has not noted any problems. The study will continue after completion of the project and any sinkhole activity will be noted and photographed.

METRIC CONVERSION FACTORS

TO CONVERT FROM	TO	MULTIPLY BY
Length		
foot (ft)	meter (m)	0.3048
inch (in)	millimeter (mm)	25.4
yard (yd)	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
Area		
square foot ($ft.^2$)	square meter (m^2)	0.0929
square inch ($in.^2$)	square centimeter (cm^2)	6.451
square yard ($yd.^2$)	square meter (m^2)	0.8361
Volume		
cubic foot ($ft.^3$)	cubic meter (m^3)	0.02832
cubic yard ($yd.^3$)	cubic meter (m^3)	
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
Mass		
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbm)	kilogram (kg)	907.2
Density		
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound- mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon(U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon(Can.)**	kilogram/cubic meter (kg/m^3)	99.78
Temperature		
degree Celsius (°C)	Kelvin (°K)	$t^{oK}=(t^{oC}+273.15)$
degree Fahrenheit (°F)	Kelvin (°K)	$t^{oK}=(t^{oF}+459.67)/1.8$
degree Fahrenheit (°F)	degree Celsius (°C)	$t^{oC}=(t^{oF}-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is the "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

TABLE OF CONTENTS

Appendices

List of Photographs

List of Tables

INTRODUCTION

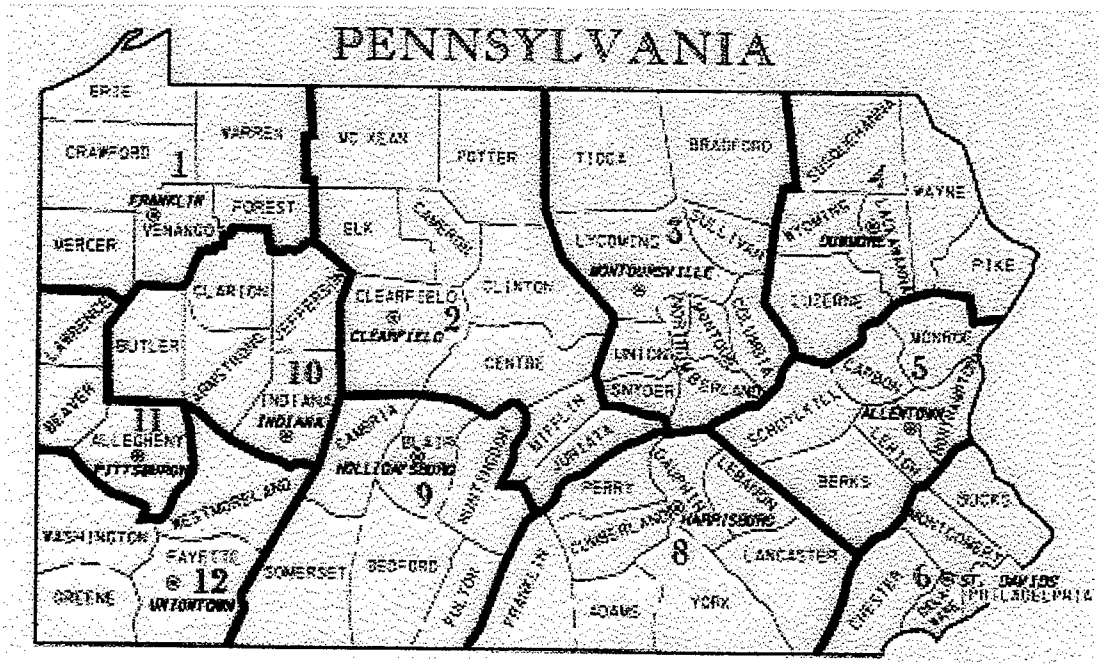
The construction of a new bypass around the town of Milroy in Mifflin County on SR 0322, Sections B01 and B02, began in the 1997 construction season. This project is scheduled to be completed in 1999, see the location map on page 2.

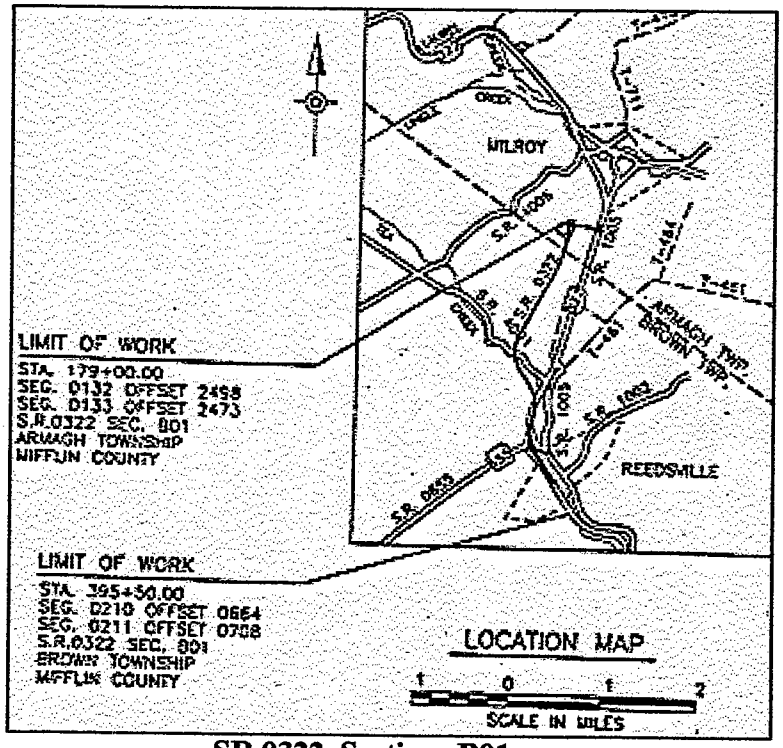
The roadway geotechnical investigation conducted during the project's design phase identified areas with a high potential for sinkhole activity. These areas were identified as anywhere the roadway alignment crossed over any limestone and dolomite geologic formations. For this reason approximately 16,000 feet of the roadway alignment is considered to have a potential for sinkhole activity.

The District proposed to install impermeable liners in all drainage ditches in sinkhole-prone areas to prevent the infiltration of surface water, a prime cause of sinkhole development. A Geosynthetic clay liner such as CLAYMAX, BENTOMAT or BENTOFIX was recommended to address this potential problem, see Appendix A on page 13 for the contract special provision and Appendix C on page 21 for the physical properties of these materials. Trumbull, Inc, the prime contractor on Section B01, elected to use BENTOFIX, a geosynthetic clay liner marketed by Fluid Systems, Inc.

This study will evaluate the constructability and performance of a geosynthetic clay liner (GCL) used to prevent the infiltration of drainage water, and to evaluate this lining method for the prevention of sinkholes within the project's drainage system. The study continued for an 18 month period after the completion of the installation.

LOCATION MAP



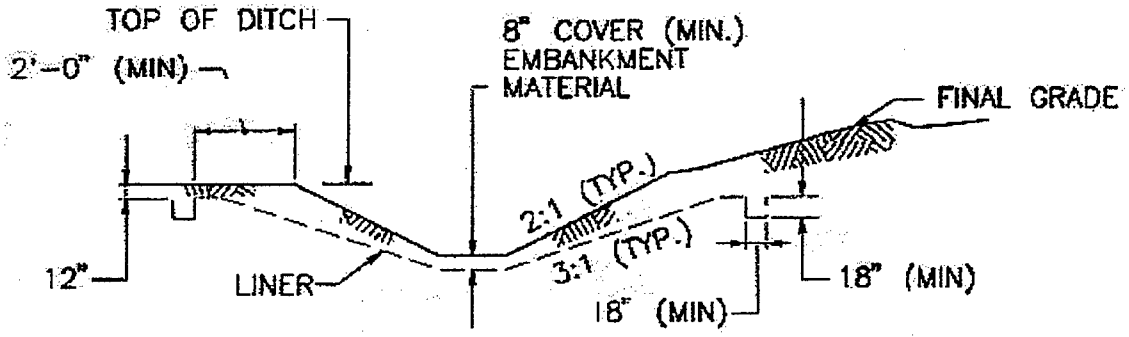


SR 0322, Sections B01
Armagh Township, Mifflin County
Engineering District 2-0

CONSTRUCTION

The project is located in Engineering District 2-0 on SR 0322 in Mifflin County. The alignment is new construction. Plan quantity for the geosynthetic clay liner for Section B01 is 32,891 square yards and the bid price was $6.25 per square yard, see Appendix A on page 13 for the contract special provision. To date 26,147.9 square yards have been placed in drainage swales at various locations on the project, see Table A on page 5.

The material is delivered to the project on rolls 15 feet wide and 150 feet long. The drainage swale is shaped as shown in photograph 1 on page 7 and as indicated on the typical section illustrated below:



GEOSYNTHETIC CLAY LINER
ITEM NO. 9000-0003
N.T.S.

The GCL is placed with a handling frame by inserting a steel bar through the core of the roll and suspending the roll from a spreader bar apparatus attached to a front-end loader or a tracked excavator, see photographs 2, 3, and 8 on pages 8 and 11. The special provision in the contract required that all GCL seams on slopes be perpendicular to the flow line at the bottom of the swale excavation, see Appendix A on page 13. These seams were to be overlapped in such a manner that the upstream liner panel is lapped over the downstream panel so as to provide a 6-inch overlap on all sides, see photograph 10 on page 12. Installation of the GCL required considerable hand work as the material had to be unrolled, cut to the required length to span the ditch transversely, and moved into final position, see photograph 5 on page 9. In some locations, it was not possible to operate the front-end loader in a direction perpendicular to the ditch. In these locations, the GCL had to be unrolled parallel to the ditch, cut to length, rotated 20 degrees by the work crew and placed so as to provide a 6-inch overlap. The contractor solved this problem by using a tracked hydraulic excavator to suspend the roll of GCL. The hydraulic excavator can be positioned to allow the GCL to be unrolled and cut to length directly over its intended location, see photographs 4 and 5 on page 9.

A minimum of 8 inches of cover or fill material is required over the GCL, see photographs 6 and 7 on page 10. Earth excavated from the ditch may be used as cover material, provided that no large stones come into contact with the GCL. The GCL must be kept dry until the installation (including cover material) is completed.

TABLE A - Geosynthetic Clay Liner Installation Locations and Quantities		
Station Location	**Date Installed**	**Quantities S.Y.**
22+25 to 23+00 RT Ramp C-3	07/11/97	229.17
20+07 to 22+25 RT Ramp C-3	08/01/97	852.44
15+39 to 17+53 RT Ramp C-3	08/07/97	511.22
18+91 to 20+07 RT Ramp C-3	08/07/97	431.78
23+00 to 24+12 RT Ramp C-3	08/07/97	311.11
75+50 to 81+50 LT	08/14/97	1600.00
81+50 to 84+50 LT	08/14/97	685.47
84+50 to 85+29 LT	08/15/97	150.36
95+70 to 102+00 LT	08/15/97	1663.30
102+00 to 102+40 LT	08/19/97	91.11
104+50 to 110+50 LT	08/19/97	1838.11
110+50 to 113+50 LT	08/20/97	1072.94
113+50 to 120+50 LT	08/22/97	2122.99
71+50 to 73+50 LT	08/23/97	522.61
120+50 to 125+15 LT	08/23/97	1125.47
125+42 to 126+82 LT	08/23/97	259.33
67+85 to 71+50 LT	08/25/97	866.76
85+29 to 86+00 LT	08/25/89	252.58
86+00 to 87+00 LT	08/26/97	404.81
125+15 to 125+42 LT	09/02/97	87.00
126+82 to 128+08 LT	09/02/97	298.27
135+50 to 137+00 RT	09/02/97	479.17
137+00 to 146+00 RT	09/09/97	3088.89
146+00 to 150+00 RT	09/22/97	961.11
150+00 to 154+00 RT	09/23/97	1022.22
18+50 to 20+50 Ramp BC	09/23/97	479.50
65+00 LT	09/25/97	32.58
64+00 to 68+00 LT	09/26/97	902.78
12+50 to 16+00 Ramp C	09/30/97	925.00
16+22 Ramp BC to 18+50 LT	10/20/97	662.00
157+17 to 159+50 RT	10/21/97	876.61
24+12 to 24+50 RT	11/20/97	110.00
63+50 to 63+73 LT	03/20/98	74.11
73+50 to 75+50 LT	03/20/98	441.66
87+00 to 87+20 LT	03/23/98	369.44
94+00 to 94+70 LT	03/24/98	345.00
174+00 to 178+00 LT	05/01/98	755.56
128+00 to 133+00 LT	05/15/98	1050.83
134+00 to 135+80 RT	05/15/98	576.67
15+00 to 15+63 LT	05/15/98	154.08
17.53 to 18+91 RT C-3	06/09/98	311.67
133+41 to 134+00 RT	06/01/98	144.22
132+50 to 135+04.5	06/11/98	450.57
135+27.8 to 138+50 LT	06/11/98	459.64
93+50 to 94+50 RT	06/26/98	133.33
138+50 to 139+29 LT	07/17/98	122.89
154+00 to 157+17 RT	08/20/98	485.51
56+06 to 61+76 RT	08/20/98	949.45
87+28 to 90+37 LT	10/16/98	770.17
101+50 to 102+60 LT	10/19/98	207.78
	Area of material placed 32,719.17 S.Y. **Plan Quantity is 32,891 S.Y.**	

Comments and Recommendations

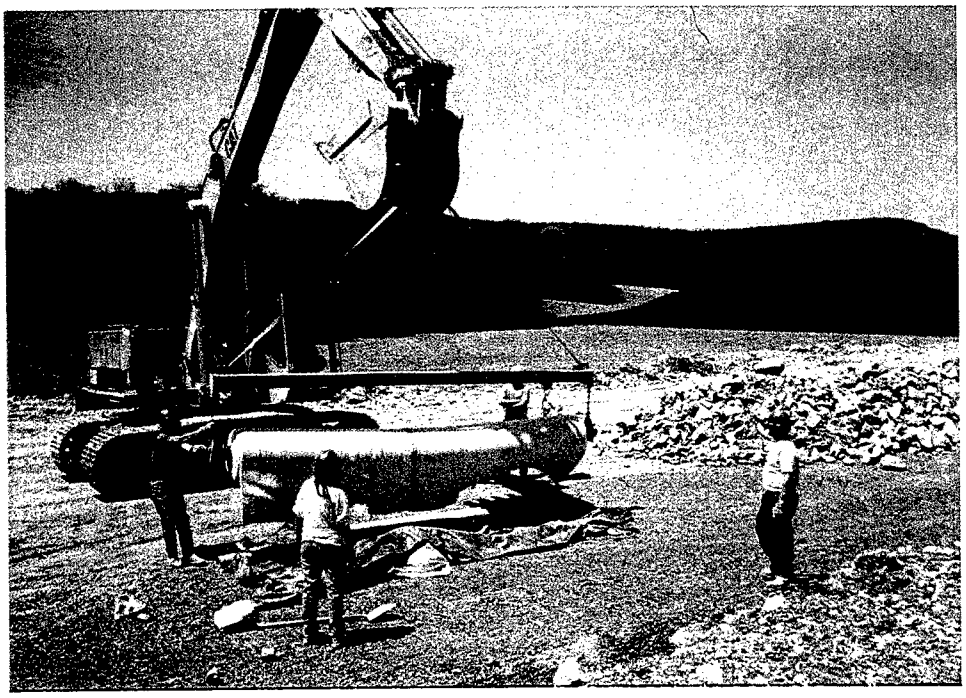
The use of geosynthetic clay liners to prevent sinkhole development in highway drainage systems appears promising. However, a precise cost-benefit analysis is very difficult. Sinkholes are site specific and expensive to repair, especially if they occur in a location that threatens the roadway pavement or a bridge foundation. Sinkholes can also allow surface water to enter the ground water supply and pollute the local aquifer. If the different brands and models of geosynthetic clay liners listed in Appendix C on page 21 prove to prevent the development of sinkholes, they can be considered cost effective.

As part of this study, the clay liner installations were monitored monthly for a period of 18 months. After this time period informal monitoring will continue indefinitely until failure occurs or the current District Geotechnical Engineer retires (which ever comes first).

PHOTOGRAPHS
SR 322, MIFFLIN COUNTY

PHOTOGRAPH 1 – The swales or drainage ditches on this project were so wide that the GCL material was placed transversely across the ditch. If the GCL material were placed longitudinally a seam would have been located at the bottom of the ditch for the full length of the ditch and would leak. This leaking water would have defeated the purpose of the GCL to contain and control rainfall runoff and reduce the potential of a sinkhole forming from water percolating into the soil. Another consideration was that a high flow condition could cause scour and unfold the center lap of the GCL. For this reason the GCL was placed in a manor similar to roofing shingles.

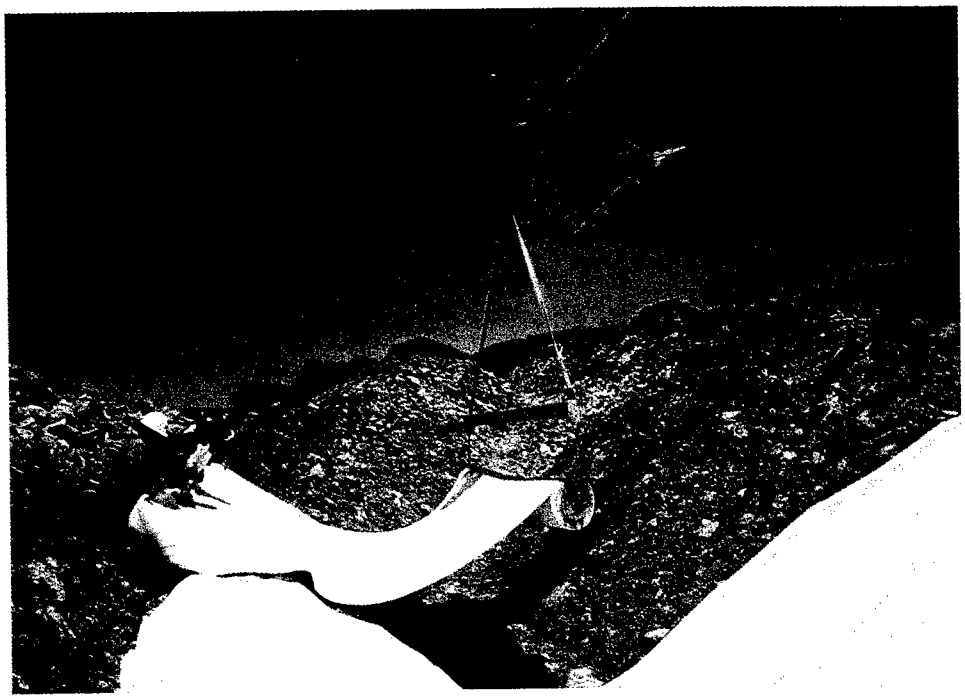
PHOTOGRAPHS
SR 322, MIFFLIN COUNTY



PHOTOGRAPH 2 – A handling frame is used to hold the roll during lifting and transporting of the GCL material during placement operations.

PHOTOGRAPH 3 – Without the frame it would be very difficult to lift and place the GCL without damaging the material. The roll weighs 2,661 pounds or 1,207 Kilograms.

PHOTOGRAPHS
SR 322, MIFFLIN COUNTY



PHOTOGRAPH 4 – During the GCL placement operations the material is placed transversely across the drainage ditch with ends being anchored in a parallel keyway ditch.

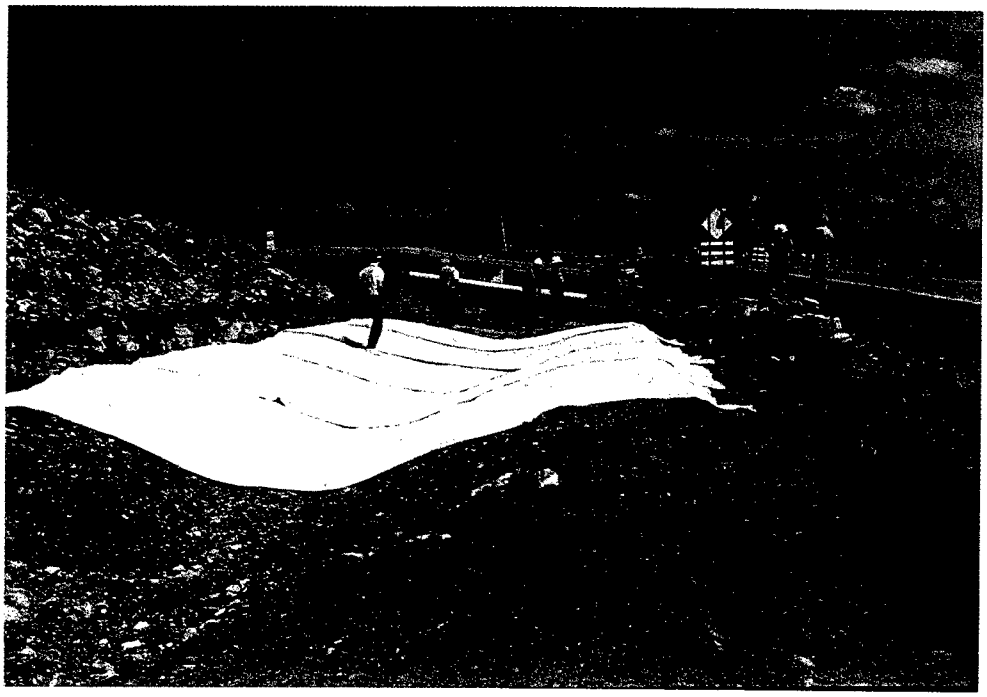
PHOTOGRAPH 5 – The GCL material is rolled out across the trench and then cut to size with enough extra material placed into a small parallel keyway ditch used to anchor the ends of the material.

PHOTOGRAPHS
SR 322, MIFFLIN COUNTY

PHOTOGRAPHS 6 – Once the GCL is positioned and placed the material is covered with a minimum 8 inches depth of cover or fill material.

PHOTOGRAPH 7 – Shows the GCL material being covered with both a loader and a tracked excavator.

PHOTOGRAPHS
SR 322, MIFFLIN COUNTY



PHOTOGRAPH 8 – Shows the GCL being placed initially with a loader and a handling frame.

PHOTOGRAPH 9 – Shows a completed drainage ditch with GCL. The Rip-Wrap was used for erosion control and to reduce flow velocities. This will ensure that the 8 inches of minimum depth of cover over the GCL stays in place. If the GCL becomes exposed to the sun the geotextile used to sandwich the bentonite clay will eventually rot from exposure to ultraviolet light and the watertight integrity of the GCL will fail.

PHOTOGRAPH 10 – The transverse seams of the GCL were to be overlapped in such a manner that the upstream liner panel is lapped over the downstream panel with a 6-inch minimum overlap provided on all sides. Granulated bentonite was placed in the seam of the overlapping GCL panels to ensure a proper seal.

Appendix A
Special Provision
For
Geosynthetic Clay Liner
SR 322-B01, Mifflin County
Engineering District 2-0

ITEM 9000-0003 – GEOSYNTHETIC CLAY LINER

DESCRIPTION – This work is the installation of geosynthetic clay liners as indicated.

MATERIAL – Geosynthetic Clay Liner – Use Claymax 500 SP geocomposite liner as supplied by ACF Environmental, 1801-A Willis Rd., Richmond, VA 232137, (800) 448-3636; BENTOMAT geocomposite liner as produced by Colloid Environmental Technologies Company, 521 E. Epson Rd., Unit 1B, Towson, MD 21286, (410) 339-7424, or 1350 W. Shure Drive, Arlington Heights, IL 60004, (847) 392-5800; or Bentofix geocomposite liner as produced by Fluid Systems, 1245 Corporate Blvd., Suite 300, Aurora, IL 60504, (800) 346-9107 or approved equal.

CONSTRUCTION – Install in drainage ditches as indicated and in accordance with manufacturer's instructions. Provide a smooth subgrade, removing protrusions and rocks larger than 2 inches in diameter. Install geosynthetic clay liner so that all seams on slopes are perpendicular to the bottom of the excavation, i.e., toe of slope. Provide 6-inch overlaps at all seams. Construct seams overlaps in such a manner that the upstream liner panel is lapped over the downstream geosynthetic clay liner so as to provide a 6-inch overlap on all sides. Staple or nail into place until cover material has been placed. Do not allow construction equipment to operate directly on the liner without the support of an adequate depth of backfill.

MEASUREMENT AND PAYMENT – Square Yard.
Includes excavation for and placement of geosynthetic clay liner.
Includes backfill over the geosynthetic clay liner after placement

APPENDIX B
Draft
Standard Special Provision
For
Geosynthetic Clay Liner

ITEM 9999-0000 - GEOSYNTHETIC CLAY LINER

DESCRIPTION - This work is the furnishing and installation of a geosynthetic clay liner (GCL), as indicated or directed.

MATERIAL -

(a) Sodium Bentonite - That meets the following:

- A minimum volumetric increase of 900% when tested according to ASTM-E946-83 standard test method for plate water absorption of bentonite.
- Swell Index of 25 ml minimum in accordance with ASTM D 5890
- Mineralogically composed of a minimum of 90% montmorillonite and be specifically graded in layers of 6 mesh and 16 mesh granules.
- Granular and continuously adhered throughout the linear and to the support fabrics so that no displacement of bentonite occurs when the liner is cut, punctured, or torn.
- Bentonite Content - 0.75 lbs/sq. ft. minimum in accordance with ASTM D 5993
- Permeability $5 \text{ X } 10^{-9}$ cm/second maximum in accordance with ASTM D 5084

(b) Primary Backing.

- Non-biodegradable, non-toxic, porous, woven, slit-film, polypropylene geotextile that meets the following:
- Tensile Grab Strength 90 lbs. per inch minimum in accordance with ASTM D 4632

(c). Secondary Backing. Highly porous, non-structural, non-woven fabric for protecting and containing the granular bentonite during installation.

(d). Bentonite/geotextile composite in rolls which have a minimum width of 13 feet.

(e). Supply Geosynthetic Clay Liner in rolls tagged with the following information:

1. Manufacture's Name
2. Product Identification
3. Lot Number
4. Roll Number
5. Roll Dimensions
6. Roll Weight

Provide to the Department from the fabricator, prior to installation of the bentonite liner, a certification (with product identification, lot number, and roll number) and signed by an authorized employee of the manufacturer indicating that the GCL material meets the required specifications.

CONSTRUCTION –

(a) General. Install in drainage ditches with 8 inch depth minimum cover over all lined areas, as indicated including overlaps at field seams and anchor trenches. Submit a proposed GCL placement method for approval by the Engineer.

Store bentonite liners in their original, unopened wrapping in a dry area. Protect from precipitation and the direct heat of the sun, especially when stored for a long period time. Store the materials above the ground surface and beneath a roof or other protective covering. Keep the bentonite liner clean and free from debris prior to installation.

(b) Grade Preparation. Provide a smooth subgrade, removing protrusions and rocks larger than 2 inches in diameter. Do not begin liner installation until a proper base has been prepared to accept the bentonite liner. Complete anchor trench excavation before liner installation begins. Uniformly compact subgrade to a minimum of 90% modified proctor density (ASTM D 1557). Do not allow construction equipment to operate directly on the liner without the support of an adequate depth of backfill as indicated.

(c) GCL Installation. Complete all excavation as indicated prior to GCL placement. Place the GCL over the prepared surface in a manner to assure minimum handling and in accordance with the manufacturer's recommendations. Install geosynthetic clay liner so that all seams on slopes are perpendicular to the bottom of the excavation i.e., toe of the slope. Place the cover fill material over the GCL immediately after placement, as indicated. All GCL placed must be covered the same day. Do not place GCL in standing water or during rain. Minimize dragging the GCL on the ground and smooth out creases or irregularities during placement. Do not allow the GCL to be stretched to fit the swale cross section or profile.

(d) Seaming. When placing adjacent panels of GCL ensure that the upstream liner panel is lapped over the downstream panel with a minimum 6-inch overlap. . Remove all dirt from the overlap area of the GCL and place a bead of granulated bentonite clay as directed by the manufacturer. Cover irregular shapes, cuts, or tears in installed GCL with sufficient material to provide twelve inches of overlap on all adjacent sides as directed

(e) Seaming in hot arid conditions. When temperatures are higher than 85° F and humidity is 20% or less, shrinkage may occur soon after placement when confined soil cover placed. Under these conditions, increase the lateral overlaps 4% of the run length plus six inches.

(f) Patching. Cover irregular shapes, cuts, or tears in installed GCL with sufficient material to provide a 12 inch overlap on all adjacent sides and cover the entire patch area with granulated bentonite clay as directed.

MEASUREMENT AND PAYMENT - Square Yard

Includes excavation for and placement of geosynthetic clay liner.

Includes backfill over the geosynthetic clay liner after placement.

ITEM 9999-0000 - GEOSYNTHETIC CLAY LINER (metric)

DESCRIPTION - This work is the furnishing and installation of a geosynthetic clay liner (GCL) for swale lining with cover material, as indicated or directed.

MATERIAL -

(a). Sodium Bentonite - That meets the following:

- A minimum volumetric increase of 900% when tested according to ASTM-E946-83 standard test method for plate water absorption of bentonite.
- Swell Index of 25 ml minimum in accordance with ASTM D 5890
- Mineralogically composed of a minimum of 90% montmorillonite and be specifically graded in layers of 6 mesh and 16 mesh granules.
- Granular and continuously adhered throughout the linear and to the support fabrics so that no displacement of bentonite occurs when the liner is cut, punctured, or torn.
- Bentonite Content - 3670 g/m^2 minimum in accordance with ASTM D 5993.
- Permeability $5 \text{ X } 10^{-9}$ cm/second maximum in accordance with ASTM D 5084.

(b). Primary Backing.

- Non-biodegradable, non-toxic, porous, woven, slit-film, polypropylene geotextile that meets the following:
- Tensile Grab Strength 400 N per inch minimum in accordance with ASTM D 4632.

(c). Secondary Backing. Highly porous, non-structural, woven or non-woven fabric for protecting and containing the granular bentonite during installation.

(d). Bentonite/geotextile composite in rolls which have a minimum width of 4.0 meters.

(e). Supply Geosynthetic Clay Liner in rolls, marked and tagged with the following information:

1. Manufacture's Name
2. Product Identification
3. Lot Number
4. Roll Number
5. Roll Dimensions
6. Roll Weight

C0NSTRUCTION -

(a) General. Install in drainage ditches with (20cm) 0.02 meters depth minimum cover over all lined areas as indicated including overlaps at field seams and anchor trenches. Submit a proposed GCL placement method for approval by the Engineer.

Store bentonite liners in their original, unopened wrapping in a dry area. Protect from precipitation and the direct heat of the sun, especially when stored for a long period time. Store the materials above the ground surface and beneath a roof or other protective covering. Keep the bentonite liner clean and free from debris prior to installation.

(b) Grade Preparation. Provide a smooth subgrade, removing protrusions and rocks larger than 0.05 meters (5 cm) in diameter. Do not begin liner installation until a proper base has been prepared to accept the bentonite liner. Complete anchor trench excavation before liner installation begins. Uniformly compact subgrade to a minimum of 90% modified proctor density (ASTM D 1557). Do not allow construction equipment to operate directly on the liner without the support of an adequate depth of backfill as indicated.

(c) GCL Installation. Complete all excavation as indicated prior to GCL placement. Place the GCL over the prepared surface in a manner to assure minimum handling and in accordance with the manufacturer's recommendations. Install geosynthetic clay liner so that all seams on slopes are perpendicular to the bottom of the excavation, i.e., toe of the slope. Place the cover fill material over the GCL immediately after placement. All GCL placed must be covered the same day. Do not place GCL in standing water or during rain. Minimize dragging the GCL on the ground and smooth out creases or irregularities during placement. Do not allow the GCL to be stretched to fit the swale cross section or profile.

(d) Seaming. When placing adjacent panels of GCL ensure that the up stream GCL panel is placed over the down stream panel with a minimum 0.16 meters (16 cm) overlap. Remove all dirt from the overlap area of the GCL and place a bead of granulated bentonite clay between the layers as required by the manufacturer. Lock the leading edge of the GCL into the anchor trench as indicated.

(e) Seaming in hot arid conditions. When temperatures are higher than 29° C and humidity is 20% or less, shrinkage may occur after placement when confined soil cover is placed. Under these conditions, increase the lateral overlaps 4% of the run length plus six inches.

(f) Patching. Cover irregular shapes, cuts, or tears in installed GCL with sufficient material to provide a (31cm) 0.031 meters overlap on all adjacent sides and cover the entire patch area with granulated bentonite clay as directed.

MEASUREMENT AND PAYMENT - Square Meter

Includes excavation for and placement of geosynthetic clay liner.

Includes backfill over the geosynthetic clay liner after placement

APPENDIX C
Geosynthetic Clay Liner Materials Specified For Sink Hole Mitigation

Geosynthetic Clay Liners (GCL) Specified for Sink Hole Mitigation

Physical Properties	**Bentomat ST**	**Bentofix Thermal-Lock NS**	**Claymax 500 SP**
Bonding Method	Needle punch	Needle punch, thermal locked	Stitch bonded
Roll Width/Length m/m ft/ft	 4.6/45.7 15/150	 4.7/45.7 15.5/150	 4.0/45.7 13.67/150
Average Roll Weights	1160 kg. 2350 lb.	1134 kg. 2500 lb.	1134 kg. 2500 lb.
Bentonite Mass/Unit Area ASTM D 5993	3670 g/m² 0.75 lb./ft.²	4390 g/m² 0.90 lb./ft.²	3600 g/m² 0.75 lb./ft.²
Flux* ASTM D 5887	1×10^{-8}	1×10^{-8}	1×10^{-8}
Swell Index (min) ASTM D 5890	24 ml/2g	24 ml/2g	24 ml/2g
Fluid Loss ASTM D 5891	18 ml.	18 ml.	18 ml.
Upper Geosynthetic			
Type of Structure	woven	PP staple non-woven	woven slit film
Weight ASTM D 3776 g/m² oz/yd²	 105 3.2	 200 6.0	 87 2.8
Lower Geosynthetic			
Type of Structure	non-woven	PP slit film woven	woven slit film
Weight ASTM D 3776 g/m² oz/yd²	 200 6.0	 105 3.1	 2.8
Permeability (max.) ASTM D 5084	5×10^{-9}	5×10^{-9}	5×10^{-11}
Hydrated Internal Shear Strength ASTM D 5321	500 PSF 24 kPa	500 PSF 24 kPa	500 PSF 24 kPa
Tensile Grab Strength ASTM D 4632	90 lb 400 N	95 lb 442 N	150 lb 660 N

*Flux is defined as "flow rate/unit area" which can be converted to permeability using the equation: Permeability = flux / hydraulic gradient.