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Department of Transportation

RESEARCH PROJECT NO. 96-054A
GEOSYNTHETIC CLAY LINER

FINAL REPORT
JULY 1998

Prepared by:
Kevin Milnes

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF CONSTRUCTION AND MATERIALS
ENGINEERING TECHNOLOGY AND INFORMATION DIVISION

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This report summarizes the performance of Geosynthetic Clay Liner for sinkhole mitigation on SR 3040-01 in Berks County, Pennsylvania. geosynthetic Clay Liner is a composite material made from bentonite clay sandwiched between woven and non-woven geotextile., This material was placed where a recurring sinkhole had appeared. The sinkhole has not reappeared since the Geosynthetic Clay Liner was placed. The Geosynthetic Clay Liner placed on this project was Bentomat ST clay liner supplied by the Colloid Environment Technologies Company (CETCO).

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RESEACH PROJECT 96-54A

"GEOSYNTHETIC CLAY LINER"

FINAL REPORT

JULY 1998
PREPARED BY:
Kevin Milnes

Conducted By:
THE PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
Engineering District 5-0, Construction Unit
and
Bureau of Construction and Materials
Engineering Technology and Information Division
Engineering Technology Section

EXECUTIVE SUMMARY

This study evaluated the ease of construction and performance of the geosynthetic clay liner (GCL) installed on SR 3040-001, Park Road Corridor, in Berks County. The purpose of this GCL was to prevent infiltration of drainage water in the areas determined to be in an elevated risk area for sinkhole activity. There was one area of the project with a recurring sinkhole problem.

The conventional Engineering District 5-0 method of sinkhole repair is as follows: The area is excavated down into the sinkhole to the bedrock to locate the eye or throat of the sinkhole; after the concrete sets, the hole is lined with a class 2 type A woven geotextile and filled with impervious clay that is compacted during placement; The top of the compacted clay backfill is also covered with geotextile; topsoil is then placed over the geotextile and the area is dressed up, seeded and mulched.

The initial plan to address the sinkhole problem was to construct the swales with a roto-tilled bentonite seal, but due to relative shallow rock profiles (a direct cause of elevated sinkhole potential), this plan was abandoned, and the GCL was then proposed.

The GCL material actually used to line the parallel and median swales, along with the bottom of the newly-constructed detention pond on this project , was the Bentomat ST clay liner supplied by the Colloid Environment Technologies Company (CETCO).

Approximately 5,300 S.Y. of GCL were installed at a cost of $53,000 or $10.00/S.Y. Eight sinkholes were encountered and repaired prior to placing the GCL at a cost well over $100,000. It is, therefore anticipated that the preventative measure of installing the GCL will prove to be cost-effective over time.

There have been some minor settling and scouring problems between STA 137+00 and STA 142+00 in the right swale due to the flow rate of water through this area. Also, wheel ruts were noted in the median, where vehicles left the roadway. Although the liner has not been exposed, the potential was present due to limited cover.

It is recommended that a minimum of one foot of material be placed over the GCL where possible. If the GCL is to be placed in a high flow rate area, provisions should be made to prevent erosion, i.e., rock-lined ditches or energy dissipaters.

There has been no evidence of sinkhole activity in the areas in which the GCL was placed. The areas have been monitored from July of 1997 to March 1998.

The Geosynthetic Lay Liner material seems to have mitigated the recurrence of any further sinkhole activity within the project area. For this reason, GCL is recommended for approval for sinkhole mitigation on all future Departments projects where this material is warranted.

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)	0.00315
gallon (U.S. 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
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		
deg Celsius (°C)	kelvin (°K)	$t^{\circ K} = (t^{\circ C} + 273.15)$
deg Fahrenheit (°F)	kelvin (°K)	$t^{\circ K} = (t^{\circ F} + 459.67) / 1.8$
deg Fahrenheit (°F)	deg Celsius (°C)	$t^{\circ C} = (t^{\circ F} - 32) / 1.8$

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PROJECT OBJECTIVE

The objective of this research project was to evaluate the ease of construction and performance of a geosynthetic clay liner (GCL) in areas where there was a shallow rock profile. These areas were determined to be an elevated risk zone for potential sinkholes.

The uncertainty of when and where the next sinkhole would form along the newly constructed roadway prompted the Department to utilize the GCL alternative. Additionally, the use of GCL to cover large areas eliminates the need for performing any major excavating, drilling, and pressure grouting operations, which would be very costly.

PROJECT SITE LOCATION

The geosynthetic clay liner was used on SR 3040-001, Berks County, Engineering District 5-0, at the following locations:

STA 147+90 to STA 153+53	(Median Swale)
STA 139+80 to STA 142+00	(Median Swale)
STA 139+73 to STA 142+00	(Left Swale)
STA 11+15 to STA 14+59	(Ramp H, Left Swale)
STA 147+00 to STA 150+49	(Right Swale)
STA 153+20 to STA 154+00	(Right Swale)
STA 147+50 to STA 152+76	(Left Swale)
STA 137+00 to STA 141+92	(Right Swale)
STA 17+35 to STA 19+02	(Ramp B, Detention Basin)

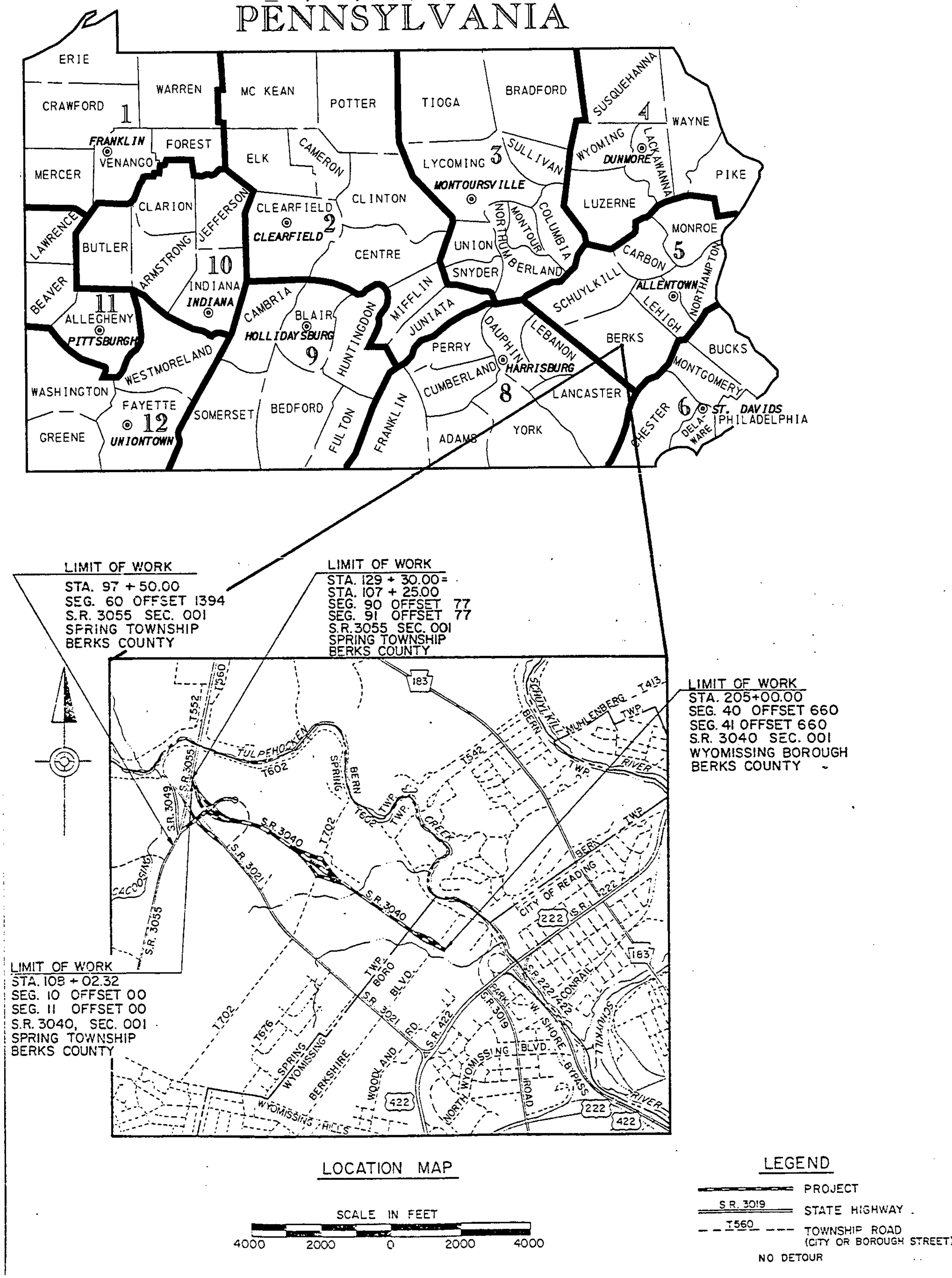
Refer to Figure 1 for the project location map.

PROJECT DESCRIPTION

The swales and detention basin, which are located in areas exhibiting a shallow rock profile and showing signs of sinkhole activity, were lined with a geosynthetic clay liner.

Due to the bedrock's close proximity to the surface, a roto-tilled bentonite seal was not practical. The clay liner was installed by removing the topsoil in the already established swale line areas, rolling the liner on grade, and replacing the topsoil.

Figure 1 - PROJECT LOCATION MAP
SR 3040-001, Berks County
Cumru Township



MATERIAL DESCRIPTION

The GCL material used on this project was Bentomat® ST, supplied by Colloid Environmental Technologies Company, 1350 West Shure Drive, Arlington Heights, Illinois 60004.

The Bentomat® ST is a reinforced GCL, which consists of a layer of Volclay granular sodium bentonite encapsulated between one woven and one non-woven geotextile material. The fabrics are needle-punched together for maximum performance under a wide range of field conditions. This material is very resilient, and will heal itself if it sustains a puncture during placement. The bentonite clay swells when it becomes wet.

The properties for the Bentomat® ST can be found in Appendix A. Appendix B explains panel and roll specifications.

CONSTRUCTION PROCEDURES

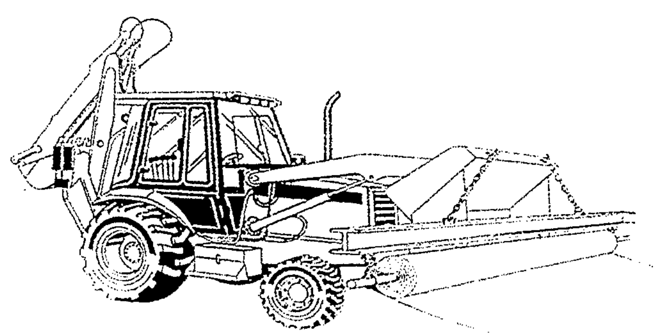
The contractor completed the installation of the GCL lining at all of the designated locations throughout the project within seven days.

The crew consisted of one superintendent, one foreman, three operators, and two laborers/truck drivers.

The equipment used was as follows: one grader, one gradall, one skid loader, one front end loader, one backhoe, one dump truck, one flat bed truck, and two pickup trucks.

The GCL was installed by grading the swale areas using the grader and Gradall (See Photo 1 through 3). Because of tight traffic conditions, a front end loader was used to haul excess fill material away from the adjacent traffic lanes. Once grade was achieved, the Bentomat® ST liner was rolled out on the grade using a backhoe with spreader and core bar attachment. Refer to Figure 2 below.

Figure 2 - Backhoe with Spreader and Core Bar Attachment



The weight of the liner material kept it in place. The windrow of material from the initial grading operation was then re-graded over the liner, and the Gradall re-established the swale line. The areas were covered with approximately six inches of topsoil, seeded, and a jute matting was placed in the swale line for erosion control.

The installation of the liner was quick and simple because the excavation did not involve penetration of the rock.

CONSTRUCTION COSTS

The material cost for the GCL was about $0.34 per square foot and was installed for $10.00 per square yard. This cost included the excavation, material, placement, and cover for this operation. The entire installation cost was approximately $53,000 to place an estimated quantity of 5,300 square yards of material.

OBSERVATIONS & RECOMMENDATIONS

To date, no sink hole activity at the locations where the GCL was installed has been observed. Some scouring and settlement problems have occurred between STA 137+00 and STA 142+00 in the right swale area due to high flow rates (See photos 14 & 16). This area will need to be redressed. Although there is some established growth in this area, it is recommended in the future, under similar circumstances, that a rock-lined swale be placed over the GCL, in lieu of topsoil and seed.

Some wheel ruts were noted in the median swale, from vehicles that left the roadway. Due to the minimal amount of cover over the GCL (6 to 8 inches), the ruts may expose the liner. For this reason it is recommended that a minimum of one foot of suitable material be placed over the liner when it is practical.

Another observation that also should also be addressed is that during the summer of 1997, there was a drought in Pennsylvania. The drought lasted several weeks. During this long period without rain, the grass within the project area dried out and became brown, except the area where the GCL was placed in the swales. The material only had six inches of cover, yet managed to maintain enough moisture to allow new grass to survive and flourish (See photo). This has little bearing on this research project but may be of interest to Departments of Transportation in the arid Southwest United States, where maintaining a grass-lined swale without irrigation may be important.

CONCLUSIONS

This research project was initiated due to the formation of a recurring sink hole on this project site. The sink hole first appeared in the swale adjacent to the location at which a cross pipe empties into the swale at STA 139+50 Rt. (See photo 12). This condition is usually repaired by excavating down into the sinkhole to bedrock, to locate the eye or throat of the sinkhole. Then the hole is filled with a few feet of concrete. After the concrete sets, the rest of the hole is lined with Class 2 Type A woven geotextile and filled with an impervious, soil-like clay. Then the site is covered with topsoil, dressed up, and seeded. This conventional method of sinkhole repair (outlined in Appendix C) could not be used due to the shallow depth to the bedrock. The Project Engineer could only fill the sinkhole with concrete, cover the concrete with topsoil, and seed the area. A few weeks after this repair was made, the sinkhole reappeared on either side of the repair area (See photo 13). These two small sinkholes were also repaired with concrete, and the GCL was installed. The Geosynthetic Clay Liner material seems to have mitigated the recurrence of any further sinkhole activity within the project area. For this reason Bentomat® ST, supplied by Colloid Environmental Technologies Company, is recommended for approval for sinkhole mitigation on all future Department projects where this material is warranted.

Geosynthetic Clay Liner is cost effective when compared to the time and expense involved in repairing a sinkhole as described in Appendix C. The use of this material could be considered an insurance policy against sinkholes and their potential for polluting the local aquifer. However, this material should only be used over soil conditions that indicate a high probability of sinkholes.

PHOTOGRAPHS

Photo 1, Initial sinkhole that appeared, 1996.

Photo 2, A grader was used to remove the topsoil in the swale.

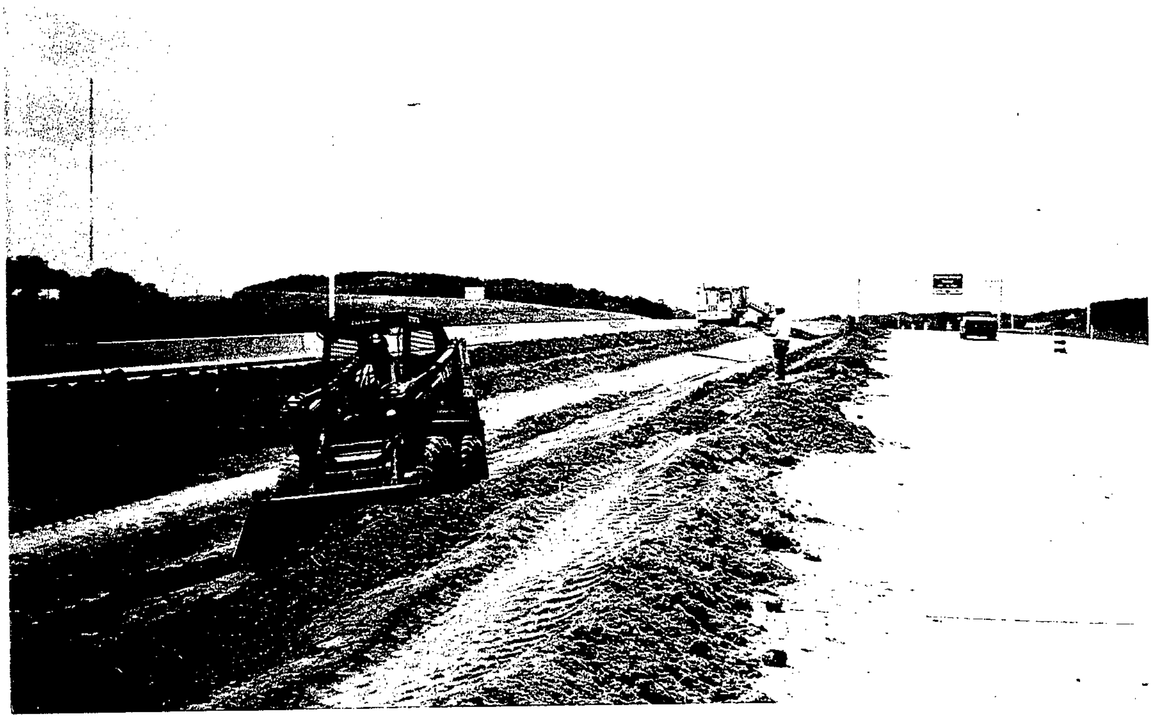


Photo 3, A skid loader was used to remove excess windrows.

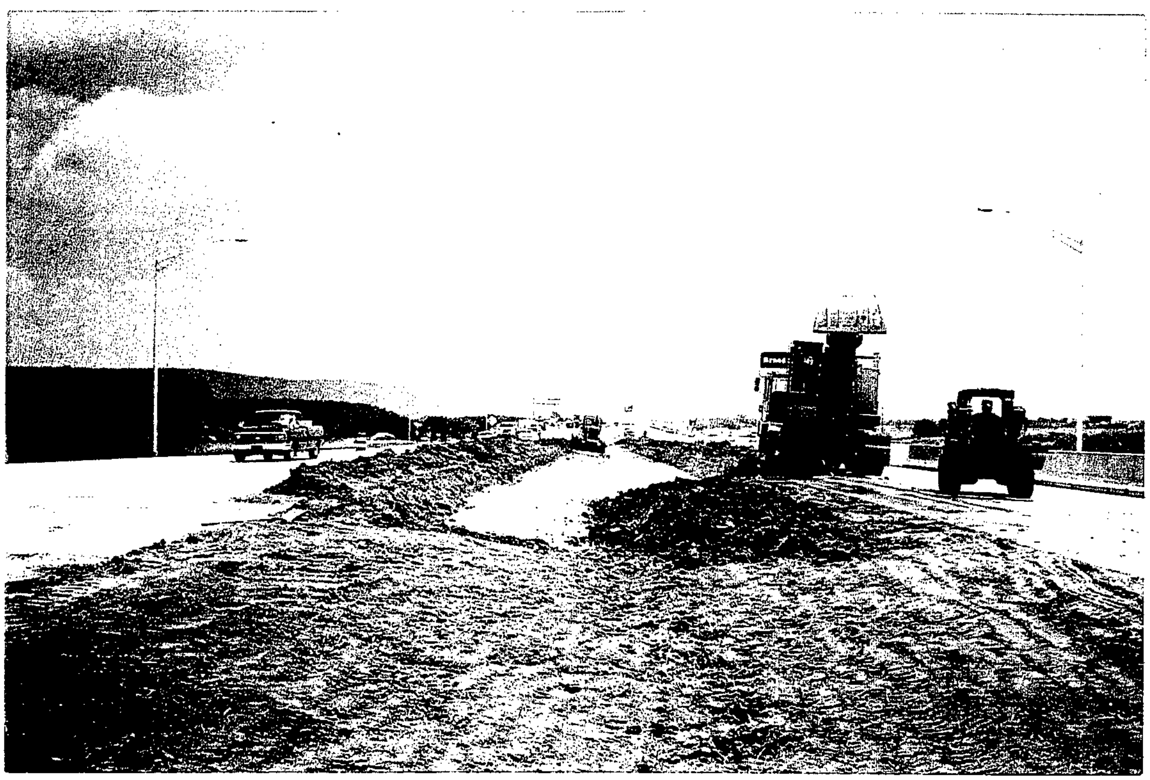


Photo 4, Shows the Gradall preparing to backfill the GCL material.

Photo 5, Final Inspection.
STA 11+15 to STA 14+59 Lt.
Ramp H

Photo 6, Final Inspection
STA 137+00 to 141+92 Rt.
Swale

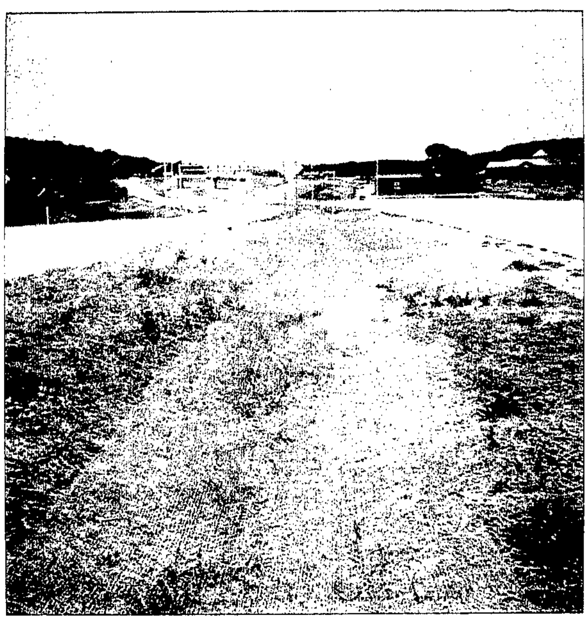


Photo 7, Final Inspection
STA 139+73 to STA 142+07 Lt.
Swale

Photo 8, Final Inspection
STA 147+00 to STA 150+49 Rt.
Swale

Photo 9, Final Inspection.
STA 147+50 to STA 152+76 Lt.
Swale

Photo 10, Final Inspection
STA 147+90 to 153+53 CL.
Median Swale

Photo 11, Final Inspection
STA 139+80 to STA 142+00 CL.
Median Swale

Photo 12, Final Inspection
STA 17+35 to STA 19+02 Rt.
Detention Pond

Photo 13, After the sinkhole was repaired, two sinkholes formed on either side of the repair at STA 139+80 Rt.

Photo 14, Shows the sinkholes that developed after the repair.

Photo 15, Shows the sloughage adjacent to the swale, where the GCL was placed.

Photo 16, Shows the GCL maintaining vegetation in the swale during a drought.

APPENDIX A
BENTOMAT "ST" CERTIFIED PROPERTIES

BENTOMAT "ST" CERTIFIED PROPERTIES

MATERIAL PROPERTY	TEST METHOD	TEST FREQUENCY, ft^2 (M^2)	REQUIRED VALUES
Bentonite Swell Index[1]	ASTM D 5890	1 per 50 tonnes	24mL/2g min.
Bentonite Fluid Loss[1]	ASTM D 5891	1 per 50 tonnes	18mL max.
Bentonite Mass/Area[2]	ASTM D 5993	40,000 ft^2 (4,000 m^2)	.075lb/ft^2 (3.6kg/m^2)
GCL Grab Strength[3]	ASTM D 4632	200,000 ft^2 (20,000 m^2)	90 lbs (400 N)
GCL Peel Strength[3]	ASTM D 4632	40,000 ft^2 (4,000 m^2)	15 lbs (65 N)
GCL Index Flux[4]	ASTM D 5887	Weekly	$1*10^{-8}$ m^3/m^2/sec
GCL Permeablity[4]	ASTM D 5084	Weekly	$5*10^{-9}$ cm/sec
GCL Hydrated Internal Shear Strength[5]	ASTM D 5321	Periodic	500psf (24kPa) typical

Bentomat "ST" is a reinforced GCL consisting of a layer of sodium bentonite betweeen a woven and a non-woven geotextile which are needlepunched together.

Notes:

[1] Bentonite property tests performed at CETCO's bentonite processing facility before shipment to CETCO's GCL production facilities.

[2] Bentonite mass/area reported at 0 percent moisture content.

[3] All tensile testing is performed in the machine direction, with results as minimum average roll values unless otherwise indicated.

[4] Index flux and permeability testing with deaired distilled/deionized water at 80 psi (551 kPa) cell pressure, 77 psi (531 kPa) headwater pressure and 75 psi (517 kPa) tailwater pressure. Reported value is equivalent to 925 gal/acre/day. This flux value is equivalent to a permeability of $5*10^{-9}$ cm/sec for typical GCL Thickness. This flux value should not be used for equivalency calculations unless the gradients used represent field conditions. A flux test using gradients that represent field conditions must be performed to determine equivalency. The last 20 weekly values prior the end of the production date of the supplied GCL may be provided.

[5] Peak value measured at 200 psf (30kPa) normal stress. Site-specific materials, GCL products, and test conditions must be used to verify internal and interface strength of the proposed design.

APPENDIX B
BENTOMAT PANEL AND ROLL SPECIFICATIONS

Technical Data Sheet

BENTOMAT PANEL AND ROLL SPECIFICATIONS

STANDARD PANEL SPECIFICATIONS

PANEL DIMENSIONS*:	15 FT. (4.6m) wide; 150 ft (45.7m) long
TOTAL PANEL AREA:	2,250 sq. Ft. (209 sq m)
EFFECTIVE AREA:	2,160 sq. Ft. (200 sq m). (Assumes 6-in. (150mm) edge overlap and 1-ft. (300mm) end overlap)

STANDARD ROLL SPECIFICATIONS

DIMENSIONS:	15.3 ft. (4.66m) wide; 24in. (610 mm) diameter
NOMINAL WEIGHT:	2700 lbs. (1225 kg)
CORE SIZE (I.D.):	4in. (100 mm). Inner core plug measures 2.5 in. (63 mm)
PACKAGING:	6-mil (0.15 mm) U.V.-resistant polyethylene sleeve

STANDARD SHIPPING SPECIFICATIONS

SHIPMENT SIZE:	17 rolls per truckload or container load
GRANULAR BENTONITE:	50-lb (23 kg) bags

UNLOADING AND HANDLING EQUIPMENT

CORE PIPE AND SPREADER BAR:	18ft (5.5M) long, 2.5 in. (63 mm) Nominal Pipe Size, XXH OR: Solid steel pipe OR: Stinger attachment for forklift
CHAINS OR STRAPS:	2 required; approximately 12 ft. (3.7 m) long each
EQUIPMENT:	Front end loader or forklift (typical)

*Custom widths/lengths available.

APPENDIX C
SPECIAL PROVISION
FOR
TYPICAL REPAIR OF SINKHOLES

TYPICAL REPAIR OF SINKHOLES IN SOIL WITH DEEP BEDROCK

This is the treatment of sinkholes where bedrock is known to be at a depth beyond 30 feet. This technique utilizes geotextile and impervious soils to "plug" the sinkhole. The geotextile prevents the migration of fines out of the soil backfill. The impervious soil prevents water infiltration. Together they form an extremely stable area over the eye of the activity. This method was developed by J, Turner, P.E., Engineering Geologist and R. Duffy, District Soils Engineer, and has been used successfully on construction sections of I-78.

EXCAVATION, GEOTEXTILE AND BACKFILL

Excavate the sink by digging down and around the open eye, trying not to cave an excessive amount of material into the eye and thus collapsing and losing it. Continue excavation down the eye until it pinches out, usually into a zone of very wet soft clay. (Occasionally, after reaching a depth of 25 to 30 feet, the eye will remain open. Additional excavation will result in a very large repair zone. In this case, place Class C Concrete and rock to plug the eye to the level of the present excavation, and continue repair as stated for pinched out eye). Isolate the zone of wet clay by excavating 2 to 3 feet into firm ground around the entire zone. Square off this initial excavation in order to simplify further work, See Figures 1-2, 2-1-A.

After the eye is isolated, begin excavation of the first bench. Start at the edges of the initial squared zone and dig into the wall at a slope of between 1:1 and ½:1 depending on the firmness of the soil. Extend this slope to a vertical height of approximately 5 to 6 feet (The height of each bench is determined by the depth of the initial excavation, for example, the depth to the bottom is 22 feet. Then the best height for each of the four benches is 5.5 feet). After reaching sufficient height, cut a flat, horizontal bench 5 feet around the entire excavation (Figures 1-3, 2-1-B & 2-4). Additional material may have to be removed above the first bench to provide safety for workers during backfilling operations.

Place Class 2, Type A Geotextile to cover the entire area of the first bench and the initial excavation (Figure 1-3). Provide sufficient overlap on the sheets to prevent any leakage (usually 1 foot). Remove any boulders or foreign material, which might puncture the geotextile, from the excavation faces. If the open eye had been plugged with Class C Concrete, place an 8 inch cushion lift of impervious soil in the bottom of the excavation before placing the geotextile.

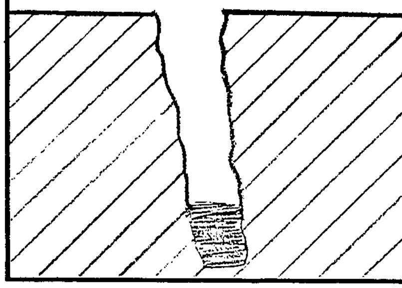
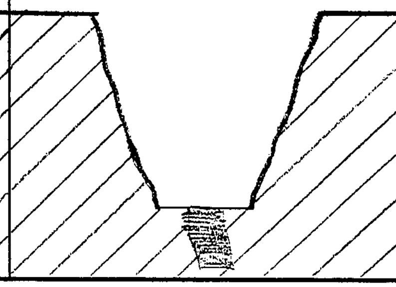
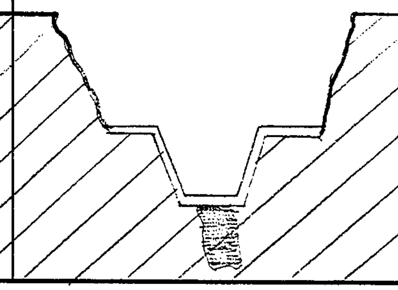
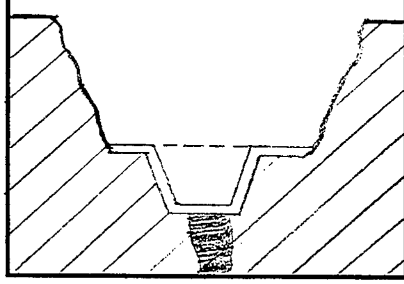
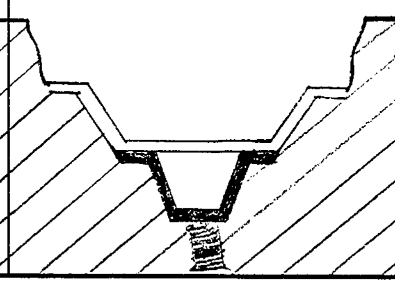
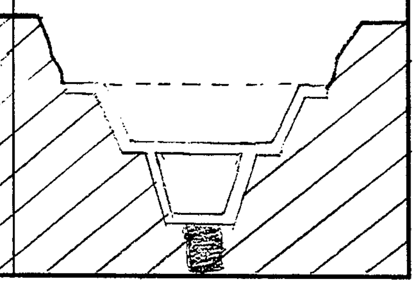
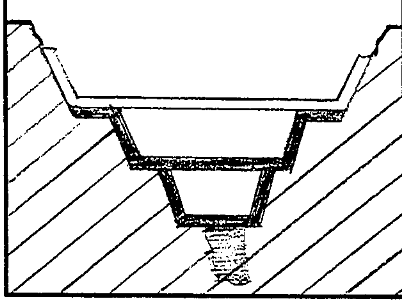
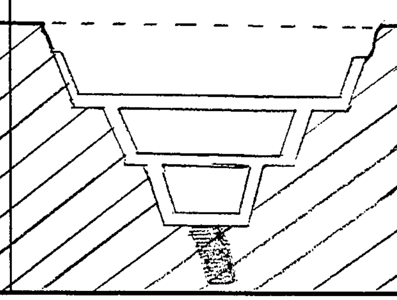
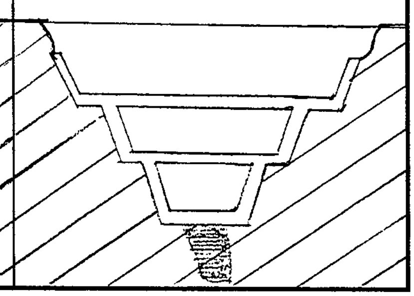
Begin backfilling the first bench. Use impervious soil, A-6, A-7-6 or A-4 with greater than 70% passing a 200 sieve. (If none of these soils are available, consider foreign borrow or a soil-bentonite mix.) Place, compact and test in accordance with Pub. 408, Sec. 206.3(b). Complete backfill level to upper lap of geotextile on first bench (Figure 1-4).

Excavate, place geotextile and backfill for second bench using the same methods as the first bench. (See Figures 1-5 and 1-6 for configuration of repair at this point). After excavation, clean any unsuitable material that may have fallen on previous backfill. When placing the geotextile for the second bench, use overlap shown in Figure 2-2 to cover the remaining geotextile from the first bench. Continue the process of excavation, geotextile and backfill for as many benches as needed until next-to-last bench is completed. For the final excavation, continue the slope up to the original ground. When placing the final geotextile layer, extend it only half way up slope (Figure 1-7). This prevents any damage to the geotextile from hauling equipment, shallow excavation or grading. Backfill to the original ground level and place the embankment, pavement or topsoil, depending on the location and elevation of the sink, to complete the repair.

Another possible variation on this is to complete all excavation and benching before beginning backfilling. This will be determined by construction conditions such as equipment availability, size of finished excavation and availability of backfill material. Use best judgment in determining the method. If completing all excavation first, simply backfill the benches as shown on figures 1-3 to 1-8.

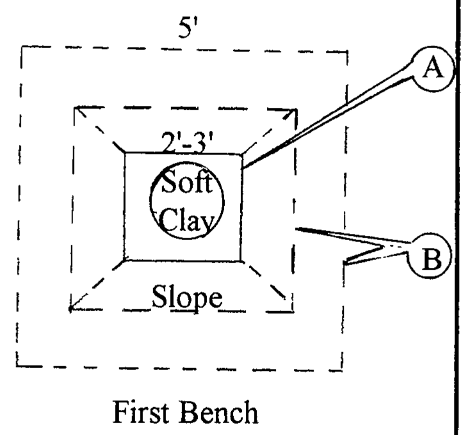
It is also possible that more than one eye may be found while excavating. Usually these will be smaller and need not be excavated, as repair of the major eye will also plug the minor eyes.

Always observe normal safety precautions when excavating and backfilling. Delineate the area to prevent any accidental falls into the excavation. Also, it is very important to prevent any surface runoff from entering the incomplete repair. Use temporary dikes, swales or other methods to control the surface waters. The completed repair should be graded to drain away from the sink area.

Existing Sinkhole in Soil	**Initial Excavation**	**Excavation of First Bench and Placement of Geotextile**
Figure 1-1	Figure 1-2	Figure 1-3
		
Backfilling of First Bench with impervious Soil (8 inch lifts)	**Excavation of Second Bench and Placement of Geotextile (Note Overlap)**	**Backfilling of Second Bench with Impervious Soil**
Figure 1-4	Figure 1-5	Figure 1-6
		
Final Excavation and Placement of Geotextile. (Note Geotextile Placed Only Half way Up Slope	**Backfilling of Final Excavation**	**Placement of Embankment, Topsoil, or Pavement**
Figure 1-7	Figure 1-8	Figure 1-9
		

Plan View

Figure 2-1



Initial Excavation (A) See Fig. 1-2
First Bench (B) See Fig. 1-3

Overlap Detail

Figure 2-2

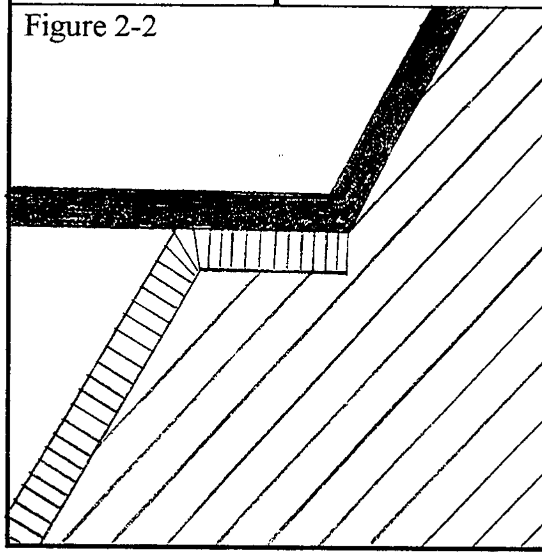


Figure 2-3

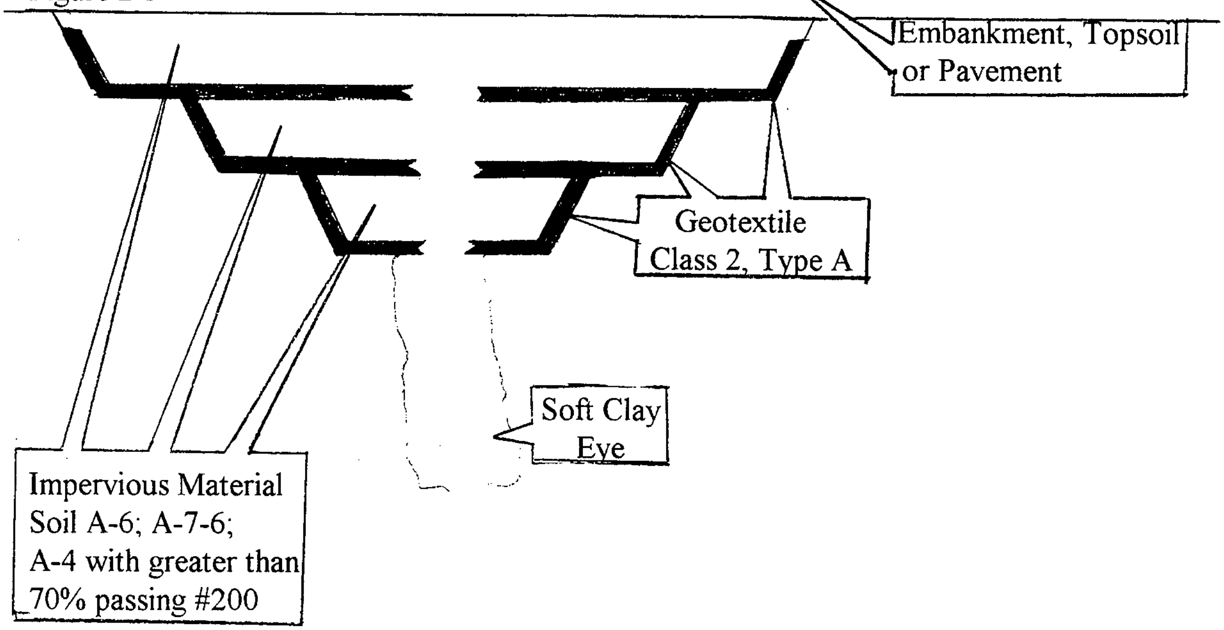
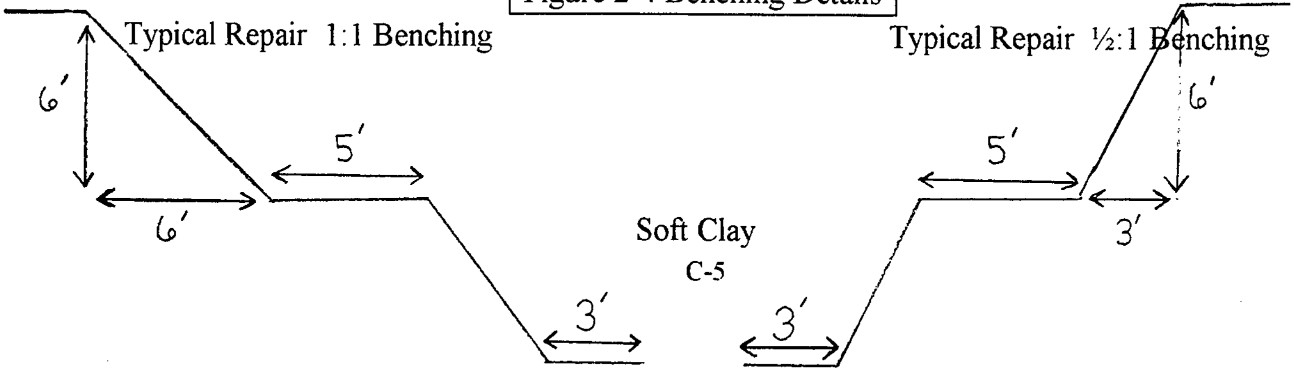


Figure 2-4 Benching Details



APPENDIX D
SINK HOLE REPAIR REPORT
ENGINEERING DISTRICT 6-0
TYPICAL REPAIR OF SINKHOLES

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
BUREAU OF CONSTRUCTION AND MATERIALS
QUALITY ASSURANCE DIVISION

REPORT TYPES SS (SINKHOLE)
DIST. 6-0 L.R. 46139 SEC. A01
COUNTY: MONTGOMERY CONTRACT NO.: 064066
REVIEW DATE: 12-14-87
TEAM MEMBER: R. BECK
CONTRACTOR: J.D. ECKMAN INC.
CONTRACTOR CODE: E007
FEDERAL AID NUMBER: NF
CONTRACT CALENDER DAYS: 10
ORIGINAL CONTRACT AMOUNT: $3,955,375.00
SPECIFICATION YEAR: 1983
CONTRACTOR'S WORK WAS IN REASONABLE CLOSE CONFORMANCE WITH THE SPEC. YES
INSPECTION WAS SUPPLYING AN ADEQUATE LEEL OF INSPECTION YES

FINDINGS & RECOMMENDATIONS

This report involves the evaluation of a sinkhole problem on a 100% state project ($3,955,375.00). The attached recommendations are a series of possible different conditions that could be encountered with a sinkhole. It should also be mentioned that one of the most qualified engineers in the area on sinkhole repairs is Elmer Shemeley. His opinion on specific problems would be of value. The recommendation for the observed sinkhole at sta. 39+15 under the temporary roadway on this project would be a noncritical area type repair. Also included in this report is a procedure developed in District 5-0 for their I-78 sinkhole problems. The procedure is good, but some of the details might not be suited for a congested urban type condition. The drawings and geotextile information is excellent in this report.

Sinkhole repairs vary depending on the amount of the overburden and soil type overlying the rock formation, and the type of rock formation (angle of the rock, if severely weathered, if boulders, or has intermittent soil seams), and if the area is either urban or rural. The following is a list of general conditions that could be encountered and some general recommendations of repair. Previous experience and knowledge of your geological conditions all help in developing a specific type of repair. Good, conservative, cost effective, engineering judgment is important in all cases.

I. STANDARD CONSIDERATIONS FOR ALL SINKHOLE REPAIRS:

1. Concrete plugs in the eye give you support at the bottom of the excavation, but the seal really comes from the geotextile and impervious material A good concrete plug lodges in eye and covers a minimum 2' bench with a thickness over the bench of 2', more if ground lacks stability.

2. The amount of area repaired is important, as other sinkholes may develop close-by in smaller, secondary eyes.

3. If you are close to the rock and/or do not control the surface water, other sinkholes will open up nearby. Surface sealing and water control are probably the best repairs for an area with large scale sinkhole activity.

4. Impervious soils can be classified as A-6, or A-4, with greater than 70% passing the 200 sieve. Clay is the best. The geotextile should be class 2, type A, with care taken in the overlapping and in the placement (so as not to puncture it).

II. A SINKHOLE IN A CRITICAL AREA WITH OVERBURDEN (near a structure, close to or under the permanent roadway. Expensive is not properly fixed and to go back in after the fact causes a problem):

1. Dig down and locate the eye, if you hit rock and /or the eye is not readily obvious, locate with water.

2. Plug with concrete, if the ground is continually falling in the eye and you can't get a two foot ledge around the eye; plug eye, then cut back two feet and cap with another layer of concrete if the bottom needs further stabilization.

3. First place a layer of soil then geotextile with 3' minimum placement of impervious material over the geotextile. Test with water to make sure it is sealed. Repeat above procedure if a new eye opens up.

4. Then a series of benched backfill operations of preferably a impervious material (clay) with intermittent layers of geotextile folded up at the edges and overlapped 1' with the next layer of geotextile. The distance between the horizontal geotextile applications can vary but 3-5' is reasonable. The amount of bench as well as the degree of the slope can vary depending on the soil conditions.

5. When you get to within 3' of the top you should test with water again to make sure that you sealed off enough of the area. If a new eye opens up, redo.

6. Seal surface & control surface water. Seal surface by covering with an impervious lay of material (clay), then geotextile, then a protective cover of soil . This type of repair can be punched through and cause future problems. Bituminous and concrete applications also seal but are more expensive. The control of the surface water is often times best done and most cost effective when paved ditches are used. Inlets and pipes sometimes cause the sinkhole situations to be aggravated during their placement phase.

III. NONCRITICAL AREAS WITH OVERBURDEN (off roadway & away from structures):

1. Dig down, find eye (about 15' but can be deeper if you run into pervious material that would cause a new eye to form or could be less if soil is good).

2. Plug with concrete (do not test with water).

3. Above recommendations on use of impervious material (clay) & geotextile backfill (do not test with water).

4. Seal surface and/or control surface water so that no new sinkholes develop.

IV. CLOSE TO ROCK WITH LITTLE OR NO OVERBURDEN (If the overburden is removed and/or doesn't exist and you are on top of rock, you have two options):

1. Pressure grouting: expensive, a very good procedure, then control surface water. There is usually some type of study done prior to using this procedure.

2. Seal surface & control surface water. Seal surface with bituminous, concrete, etc. Or by covering with an impervious lay of material (clay), then geotextile, then a protective cover of soil. This type of repair can be punched through and cause future problems. Control the surface water.

V. EXCAVATION IN SINKHOLE AREAS:

1. If the project has excavation in a known sinkhole area, the project can take precautions to control the water with retention basins. The water should then be removed in a manner that avoids cost of additional drainage is usually the more cost effective alternative in urban areas. In rural areas, with large areas to be excavated, it can be more cost effective to allow them to develop and fix them after the excavation is completed.