National Research Council

PROPOSAL COVER SHEET - IDEA Programs

(Note: The total length of IDEA proposals shall not exceed 25 pages, including the cover sheet and all enclosures)

Proposal Submitted to: [ ] Safety-IDEA [X] NCHRP-IDEA [ ] HSR-IDEA [ ] Transit-IDEA

For Use by TRB	Date Received	Proposal Number

Title of Project Geocomposite Capillary Barrier Drain (GCBD) for limiting moisture changes in pavements: Product Application	[ ] Concept Exploration (Type 1) [X] Product Application (Type 2) Project Duration ___24_____ months
Submission Date: August 27, 2004	Signed, unaltered, NRC liability certification enclosed with the proposal [X] Yes [ ] No

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	IDEA Budget $ 98,389 + Cost Sharing/Pooled funding $166,611 = Total Project Cost $265,000	

Business Type	Size (Number of Employees)
[X] Academic [ ] Profit [ ] Non-Profit	[ ] <10 [ ] <100 [ ] <200 [X] >200

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Brief Summary of Concept and Potential Impact on Practice

The proposed effort will facilitate the transfer of the Geocomposite Capillary Barrier Drain (GCBD) technology to engineering practice. The GCBD is a method for improving the sub-surface drainage from pavement sections by inducing unsaturated drainage. Using a GCBD will reduce the equilibrium water content in the base, prevent wetting of the subgrade and will increase pavement longevity. The proposed project includes demonstration and documentation of GCBD fabrication, field installation and performance monitoring at a field test track facility, and the development of the capability to incorporate the GCBD in subsequent designs.

Geocomposite Capillary Barrier Drain (GCBD) for limiting moisture changes in pavements: Product application

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Summary of Concept and Impact on Practice

Concept and innovation

The Geocomposite Capillary Barrier Drain (GCBD) is a method to suck water out of soil—that is, provide drainage while the soil is unsaturated. When placed between a base and subgrade, it can drain the unsaturated base and reduce its water content as well as prevent water from reaching the subgrade. In contrast to the GCBD, conventional drainage is designed for saturated flow, even though the positive pore water pressures required for saturated flow reduce strength and lead to rutting, heaving, and failure.

The geocomposite capillary barrier drain (GCBD) comprises three layers that are, from top to bottom: a *transport layer* (a specially designed geotextile), a *capillary barrier* (a geonet), and a *separator* (geotextile). The principal function of the GCBD is illustrated in Figure 1. Water infiltrating through the base is prevented from moving into the underlying subgrade by the capillary barrier formed by the geonet. The transport layer (a special geotextile) becomes increasingly hydraulically conductive as it wets. If the GCBD is on a slope, water will drain along the slope in the transport layer. If the transport layer does not become saturated, no water will break through into the capillary barrier. The bottom separator protects the geonet from becoming filled with subgrade soil. The GCBD also cuts off capillary rise of water in the underlying soil, and if the overlying base and transport layer become saturated due to an extraordinary infiltration event, it provides saturated drainage in the geonet.

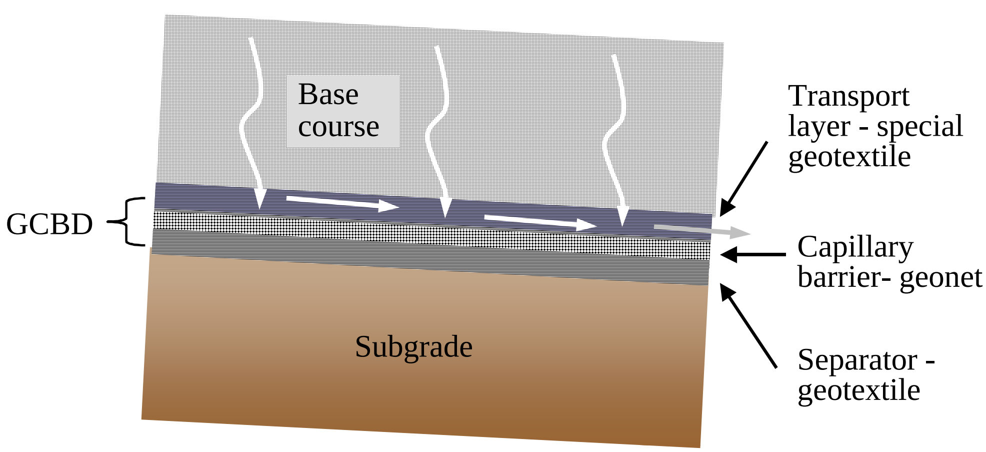


Figure 1 – GCBD between base course and subgrade illustrating how water laterally drains in transport layer.

The GDBD resembles a conventional drainage geocomposite; however, the transport layer is designed to transmit water under negative water pressures. The unsaturated hydraulic properties of the transport layer are critical to the proper functioning of the GCBD.

Potential impact and payoff for practice

The problems associated with excessive moisture in pavement bases and subgrades are numerous and well known. Conventional drainage may not be wholly effective in reducing water-related problems (e.g., Christopher and McGuffey, 1997; Hall and Correa, 2003). Conventional drainage is designed for saturated conditions, however, most water movement near the surface occurs under unsaturated (partially saturated) conditions. Recent studies suggest that conventional drainage systems can only be understood if unsaturated flow principles are considered (Birgisson and Roberson, 2000; Stormont and Zhou, 2004).

Utilizing a GCBD for pavement drainage explicitly accounts for unsaturated flow, and will result in greater drainage efficiency compared to conventional drainage. With a GCBD, the base and subgrade will contain less water than a pavement without a GCBD at any point in time. This is important because the strength of both the base course and subgrade degrades with increased moisture, and ultimately reduces pavement structural durability. Thus, a GCBD will result in increased longevity of the pavement. Expected benefits of the GCBD include:

- Reduced equilibrium water content in base
- Prevent positive pressures in base
- Prevent wetting of underlying subgrade due to infiltration
- Prevent capillary rise of water from subgrade into base
- Provide complementary separation and stabilization

Quantifying these benefits is the outcome of this proposed project.

Product transfer and implementation

This is a Type 2 proposal, and is geared toward implementing GCBD technology. A key element of the proposed project is to select the most effective transport layer for use in a prototype GCBD. The manufacturer of the transport layer will help us address issues related to costs and commercial availability. A second key element of the project is incorporation of the prototype GCBD into a full-scale test section at MnROAD, a comprehensive pavement test track facility. In addition to demonstrating construction using the GCBD, measurements of GCBD test section performance, side-by-side with a control section will quantify its benefits. Finally, design tools will be developed to aid in the design of the GCBD for specific climate, geometry, and soils. Our strategy for product transfer and implementation is summarized in Table 1.

TABLE 1 – Product transfer and implementation issues, strategies and outcomes.

ISSUE	STRATEGY	OUTCOME
Product availability and cost	A variety of prototype transport layers will be evaluated for use in the GCBD.	Cost and performance information.
Ensure product is compatible with construction practice	Install prototype GCBD at existing full-scale pavement test track facility.	Demonstration of construction methods in full-scale application.
Defining the explicit benefit of product	Measure drainage performance and pavement quality indicators (e.g. FWD) with direct comparison to control section.	Documented drainage performance and impact on pavement quality measures.
Incorporating product into design process	Develop design tool for GCBD based on field measurements.	Design capability for GCBD applications for different climates, pavement sections, etc.

Investigative Approach

This is a collaborative project among three organizations: the University of New Mexico (UNM), the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), and the Minnesota Department of Transportation (MnDOT). UNM is the lead institution for the IDEA project with CRREL funded in part as a subcontractor to UNM. MnDOT is participating by providing substantial in-kind resources. In addition, a pooled fund study is being established to support this project.

The overall purpose of the proposed project is to facilitate the transfer of the GCBD technology to engineering practice. This will be accomplished through demonstration and documentation of GCBD fabrication, field installation and performance, and the development of the capability to incorporate the GCBD in subsequent designs. The project is organized into three stages (Figure 2). Each successive stage is built upon the product of the previous stage. In the first stage, a prototype GCBD for subsequent field deployment will be developed in conjunction with the manufacturer of the transport layer. The second stage will consist of the construction and monitoring of a test section at MnROAD that includes the prototype GCBD. The third stage will use the field data to develop and calibrate a design tool for GCBD applications subject to different climatic, soil, and pavement conditions.

The project is scheduled for 24 months. Included in this time is the collection of at least one year of field data from test sections at MnROAD that include the GCBD.

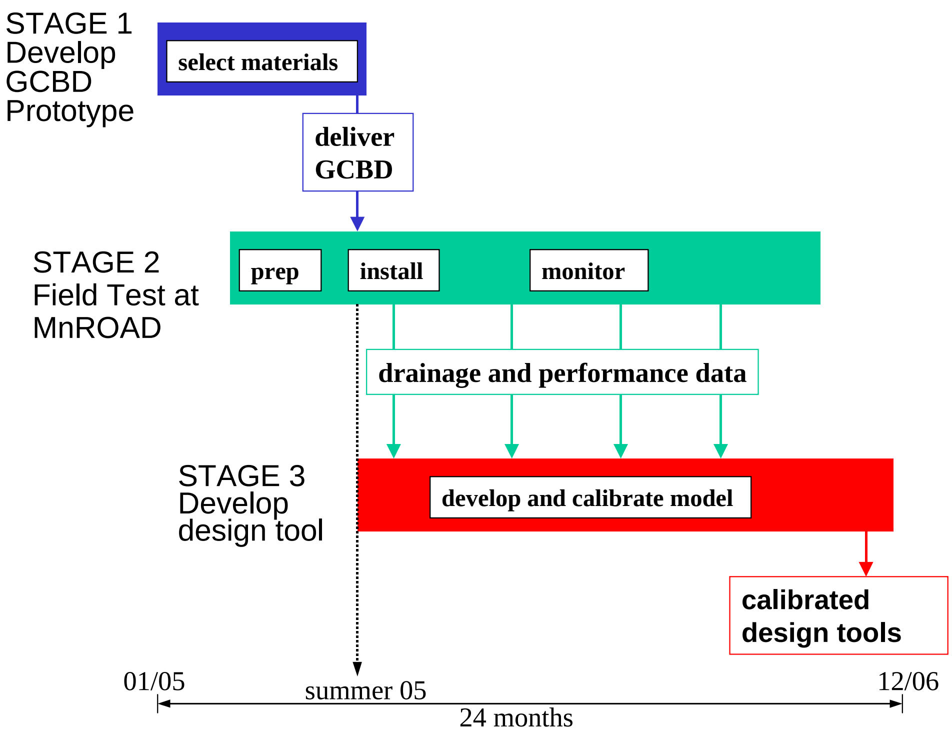


Figure 2 – Schedule for stages of proposed work

Stage One – Prototype GCBD development

Introduction and background

Previous research and development sponsored by the IDEA program has shown that the GCBD drains water from unsaturated soils (Henry and Stormont, 2002; Henry et al., 2002; Stormont et al., 2001). An important conclusion from this work was that the performance of the GCBD is controlled by the unsaturated hydraulic characteristics of the transport layer.

During the GCBD Type 1 IDEA project, we obtained 16 textile samples for evaluation as the transport layer. The samples included a wide range of products, and included textiles fabricated from polypropylene, nylon, polyester, silica and fiberglass fibers. We used the following measurements to select the best transport layer from these candidates: (1) capillary rise, (2) moisture retention functions, (3) siphon tests, and (4) unsaturated transmissivity measurements.

A material designated as TGLASS was selected as the best transport layer from the original 16 materials tested because it maintained transmissivity over a large range of suctions. It is a very heavy, woven, multifilament material with a mass per unit area of 2370 g m^{-2}, a thickness of 3.2 mm, and an O_{95} size of 0.075 mm. TGLASS performed very well in the Type 1 IDEA project. TGLASS is a commercial-grade industrial insulator, and its cost as presently manufactured is much greater than conventional geotextiles, by a factor of about ten. Some of this cost is due to economies of scale related to the limited quantities required for its usual applications. It would greatly facilitate the use of the TGLASS-based GCBD if it can be produced at a substantially lower cost or if a similar, less expensive material could exceed its performance. Thus, identifying an alternative material comparable or better than the TGLASS material is a principal objective of this stage of the proposed work. The manufacturer of TGLASS is presently working towards producing such materials that we will assess.

Work Plan

Select best possible transport layer - We have learned much about which materials are most likely to be effective as a transport layer, and have discussed this with the TGLASS manufacturer, who has the capability to produce these materials. Because of the potential for a large market, the TGLASS manufacturer is interested in possibly licensing the GCBD patent and has agreed to supply us with a variety of candidate materials for assessment.

Evaluation of the samples will be accomplished by means of laboratory capillary rise and siphon tests to assess their utility as potential transport layers. Performance will be compared against that of TGLASS. Information on cost of candidate materials will also be obtained. Up to 20 samples provided by the TGLASS manufacturer and possible other sources will be evaluated.

If a material comparable or superior to TGLASS is identified, a complete suite of characterization tests will be conducted, including unsaturated transmissivity and moisture characteristic curve. Methods for conducting these tests were developed during the Type 1 IDEA project (Henry and Stormont, 2002; Stormont et al., 2001; Stormont and Ramos, 2004). These tests are required to provide properties for subsequent evaluation of field test results.

Drainage collection system - An important issue for full-scale GCBD deployment concerns how water is removed from the GCBD and routed into a central drainage collection system. The GCBD will terminate in an edgedrain in order to collect the laterally drained water from the GCBD. Different terminus configurations will be evaluated in laboratory tests of the edgedrain using facilities previously developed for laboratory drainage tests of the GCBD (Figure 3). An edgedrain will be constructed in a manner similar to that used at MnROAD with a 4-inch plastic pipe and a gravel backfill. Water will be infiltrated into the top of the model, and laterally diverted in the GCBD to the edgedrain. The efficiency of water collection from the GCBD into the pipe will be evaluated by measurement of drainage along with water content changes in the adjacent soil. Possible modifications to the standard edgedrain configuration include longitudinally slotting the pipe to accept the GCBD and lining the edgedrain bottom with a geomembrane.

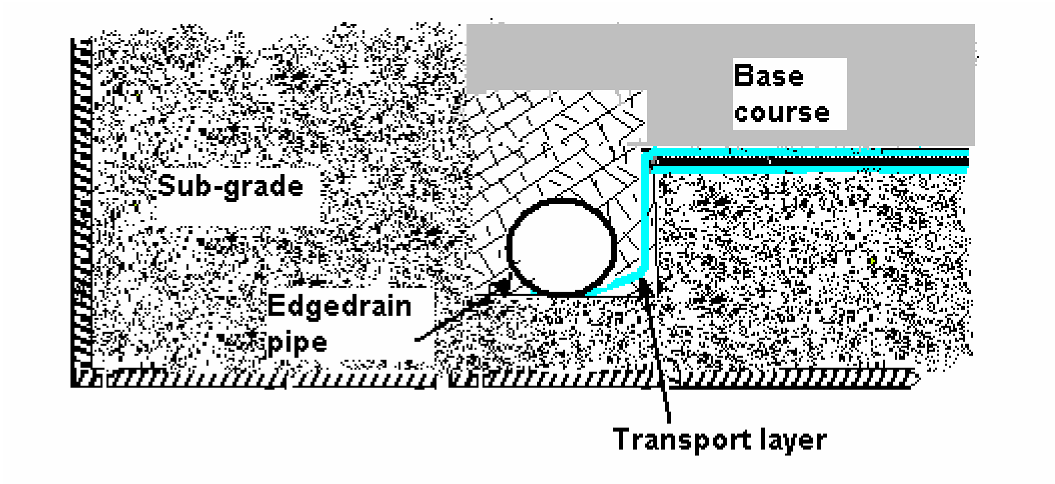


Figure 3 - Schematic of laboratory configuration used to investigate water collection from GCBD into longitudinal pipe.

Outcomes from Stage 1

The principal outcome from Stage 1 will be the design and delivery of a prototype GCBD drainage system to the MnROAD facility for field installation in Stage 2. This GCBD will be constructed with either TGLASS or a comparable material for the transport layer. Accompanying the GCBD will be suggested procedures for the field installation, including the terminus detail. GCBD cost and fabrication data and information will also be produced from this stage. All data, observations, analyses, and conclusions from this stage of the project will be contained in the summary report for Stage 1.

Schedule and approximate budget

Selection of the optimal transport layer will be accomplished by March 1, 2005. The prototype GCBD will be delivered to the MnROAD facility by June 1, 2005. The Stage 1 report will be complete by July 31, 2005. The budget for this stage includes all of the activities required to produce and characterize the prototype GCBD. Costs are approximate.

Table 2 – Stage 1 activities, lead project personnel and approximate costs.

Activity	Lead project personnel	Budget (approximate)
Test and characterize samples	Stormont	$10,000
Investigate terminus detail	Stormont	$15,000
Work with manufacturers to produce samples and prototype GCBD	Henry	$35,000
TOTAL FOR STAGE		**$60,000**

Stage Two - Field test at MnROAD

Introduction and background

The performance of GCBD systems has been evaluated in the laboratory and in a limited field test (in the Muddy Roads project). As part of Phase 1 testing in the Type 1 IDEA project, a GCBD with the TGLASS transport layer was evaluated in the 3-m-long lateral diversion device (Henry and Stormont, 2002). The unsaturated hydraulic properties of the GCBD using TGLASS was substantially improved when compared to a test with a different transport layer. At an average long-term infiltration rate of 0.15 mm hr^{-1}, the GCBD drained all infiltrating water from the overlying soil at suctions of 120 mm and greater.

In Phase 2 of the Type 1 IDEA project a test pavement was constructed that included a GCBD with the TGLASS transport layer placed between the base and subgrade on a 5% grade (Henry and Stormont, 2002). The test section was built within a waterproof box that contained a 1.3-m-long lane of pavement structure from the centerline, across an unpaved shoulder and through the bottom of a ditch. At long-term steady-state infiltration rates of 0.1 to 0.15 mm hr^{-1}, the GCBD prevented all infiltrating water from reaching the subgrade. The transport layer drained infiltrating water from overlying base at a minimum of 100 mm of suction head after water was applied. After a high-intensity 6-hour duration storm, a small amount of water broke through into the subgrade; however, the GCBD recovered its function and protected the subgrade in a subsequent test that simulated a high-intensity 1-hour storm.

In a low volume, unpaved road in Windsor, Vermont, a 100-ft-long test section containing a GCBD at a depth of 1 foot was constructed in the fall of 2001. The performance of this test section compared to adjacent control sections was evaluated by taking dynamic cone penetrometer measurements to estimate California Bearing Ratio (CBR) values. The estimated CBRs indicated that the GCBD section recovered strength significantly more rapidly than both of the adjacent controls during both thaw seasons (Henry, et al, in review).

The next step in GCBD development is to document its drainage performance in a field scale pavement section and to obtain related mechanical performance indicators. Field scale testing includes conditions that are more realistic for the eventual deployment of the GCBD technology, including pavement cracks and variability in base course properties. Field scale testing should include a side-by-side comparison with a control section. In this way, the benefits of the GCBD can be clearly demonstrated.

The principal types of measurements that will be used to assess the drainage performance of the GCBD are water contents, soil moisture tensions and collected drainage. The water contents and soil moisture tensions will provide data to assess unsaturated flow, and the changes in the amount and movement of water within the base course and subgrade due to the GCBD. The drainage measurements will provide a direct measure of drainage efficiency.

It is important to quantify the benefit of the GCBD not only in terms of drainage and water contents, but also with respect to properties that are commonly used to assess pavement performance. To this end, deflection testing and surface distress measurements will be conducted on pavement sections with and without the GCBD.

Work Plan

A key element of this proposed project is a field installation and testing of the GCBD at the MnROAD research facility, an outdoor pavement research facility located 45 miles northwest of Minneapolis, Minnesota. There are 51-instrumented concrete and asphalt pavement test sections at MnROAD representing a broad range of materials and designs. MnROAD has the staff and on-site equipment to support the construction and testing of the GCBD within a pavement section under real-life traffic loading conditions.

Construction and installation - A 500-foot test section on MnROAD's low volume loop will be utilized to test the prototype GCBD. This test section consists of two 14-foot lanes and 12-foot wide shoulders with a lateral grade of 1-2% (Figure 4). One half of the test section length will incorporate the GCBD; the other half will be the control section. Water draining laterally from the test section will be collected in an edgedrain and routed to a sump for measurement.

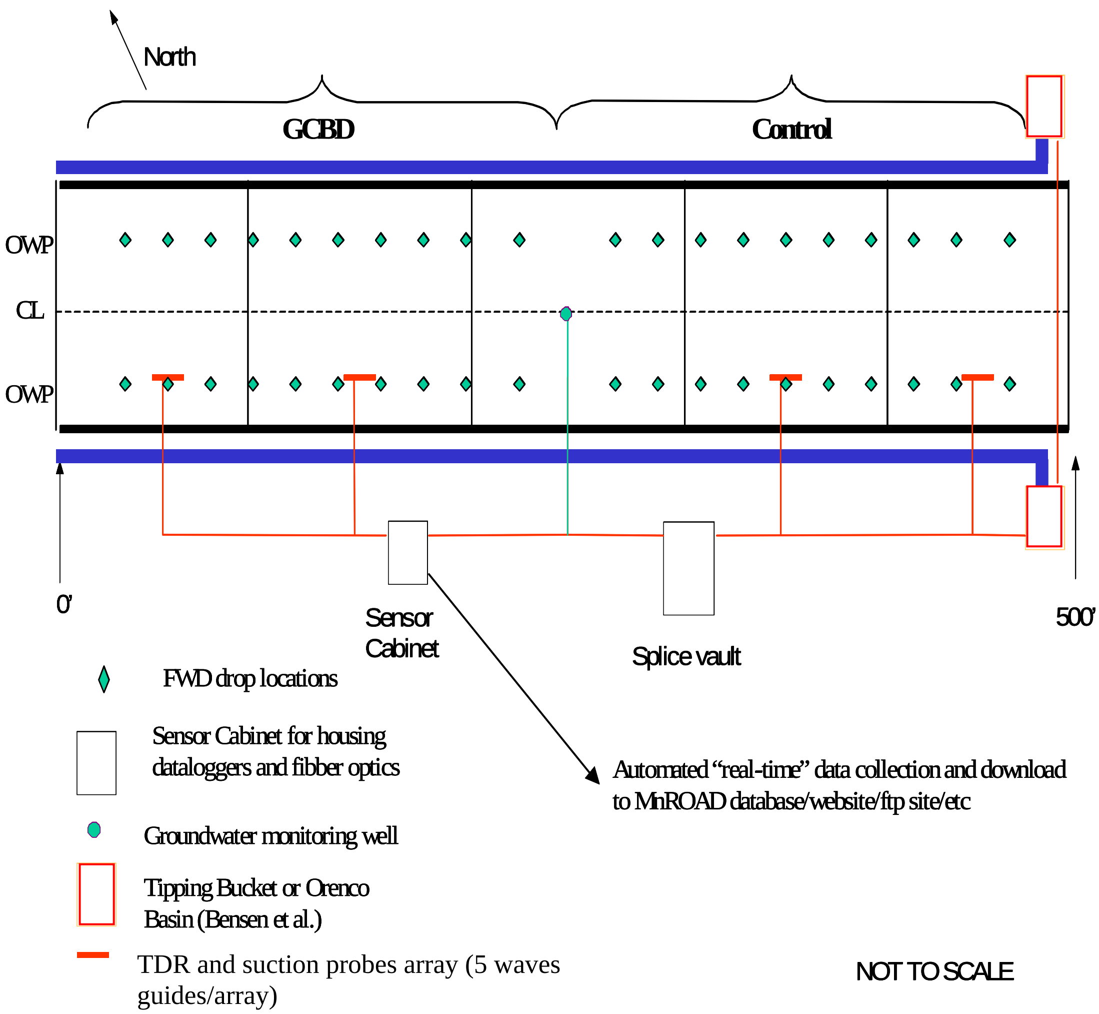
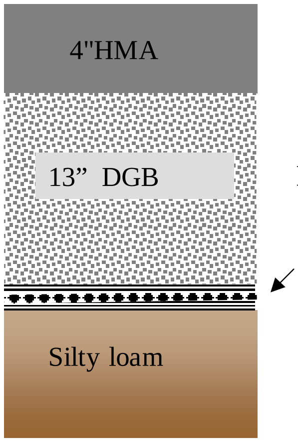


Figure 4 – Plan view of test section.

The structural layers of the test section consists of 4 inches of Hot Mix Asphalt, 13 inches of aggregate base over a clay subgrade (Figure 5). The GCBD will be located between the base and the subgrade. Material specifications are given in Figure 5.



Hot-mix asphalt (HMA)
4 inches HMA placed in two, two-inch lifts, two lanes, 14 foot wide each. Specification: MnDOT 2360 Hot-Mix Asphalt

Dense graded base (DGB)
13 inches dense graded base MnDOT spec 3138

GCBD
Placed on half of test section

Aggregate shoulders
MnDOT Class 1,2 or 6 shouldering aggregate

Figure 5 – Cross-section of proposed test section.

Instrumentation for monitoring water content, soil moisture tensions, temperature, and water table depth will be installed in the pavement subsurface during construction. Sensor arrays totaling 20 water content probes and 20 thermocouples will be installed within the control and GCBD sections at two locations. In each array, sensors will be located in the middle of the base course, just above and below the base course/subgrade interface, and 6-inches into the sub-grade. Two longitudinal edge drains terminating at the headwall of tipping bucket enclosures will be installed in the test section to collect and measure drainage. A ground water monitoring well consisting of 10 feet of screened PVC and approximately 5 feet of solid PVC will be installed at the centerline of the test section, and extend 15 feet below the surface of the pavement. All instrumentation will be connected to a data acquisition system and data collection will be automated. Data will be loaded to the MnROAD database on a daily basis.

At the conclusion of the construction of the test section, a construction report will be produced that provides as-built configurations, costs and effort associated with the GCBD installations, along with initial field observations and data.

<u>Measurements and data collection</u> - A falling weight deflectometer (FWD) will be used to measure pavement deflections and elastic response of the pavement foundation layers. The FWD method of deflection testing consists of generating a deflection basin by applying an impulse force to a load plate and measuring pavement response, or vertical velocities, with sensors placed at the surface (Figure 6). Elastic properties of the pavement layers are calculated using load and surface deflection data (Bendaña et al., 1994). MnROAD FWD testing includes 20 locations per test section (10 per lane in the outer wheelpath).

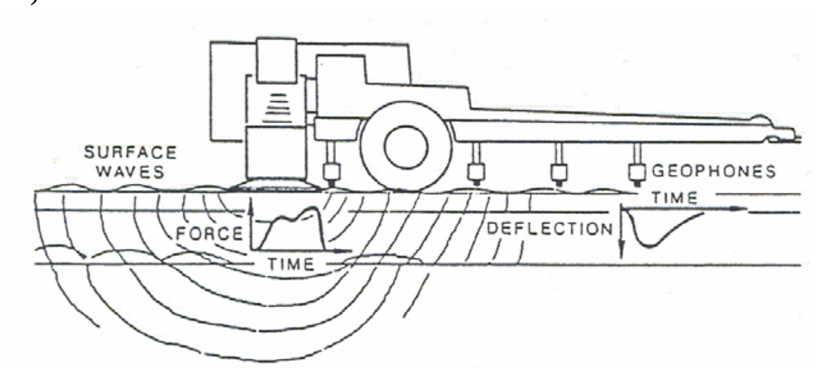


Figure 6 - FWD impulse force traveling through the deflection basin (Bendaña et al, 1994).

A distress map of the test section will be developed from visual observations, and updated on a monthly basis coincident with the FWD testing.

Data collected from the data acquisition system, field testing, and field observations will be summarized in quarterly reports. A yearly report will be produced and will contain the research results, including all data, observations, analyses and interpretations.

Outcomes from Stage 2

This stage of the project will provide a comprehensive dataset of drainage and pavement performance data related to the use of the GCBD; these data will be made available to developers of pavement design tools. The principal products from this stage are a construction report and a subsequent data evaluation report. The construction report will contain observations, data and evaluation of the field installation of the GCBD. The focus of this report will be on practical construction-related issues associated with field installation of the GCBD. A data evaluation report will be produced that will utilize data collected at MnROAD, including data collected from the automated data acquisition system as well as FWD and pavement distress data along with any other observations.

Schedule and budget

The construction is scheduled for June 2005, and expected to take one month to complete. The construction report will be completed by September 2005. The data evaluation report will be based on a year of data, and will be completed by September 2006. The budget for this stage includes all of the construction activities, including instrumentation cost, along with subsequent data collection, evaluation and reporting. Costs are approximate.

Table 3 – Stage 2 activities, lead project personnel and approximate costs.

Activity	Lead project personnel	Budget (approximate)
Construction including instrumentation	Roberson	$100,000
Conduct pavement evaluation tests and report all data	Roberson	$15,000
Evaluate drainage data	Henry	$35,000
TOTAL FOR STAGE		**$150,000**

Stage Three - Develop and apply design tool

Introduction and background

The GCBD will increase the rate and amount of drainage from the pavement system. It is necessary for designers to be able to reasonably predict the amount of increased drainage. In addition, there will be lower equilibrium water contents in the pavement foundation layers compared to typical pavement, which will affect mechanistic pavement design. Thus, there is a need for a design tool that can predict drainage and water contents in pavement systems that include a GCBD.

Drainage within a pavement system, including those with a GCBD, can be generally simulated with existing unsaturated flow codes (e.g., Stormont and Zhou, 2004; Apul et al., 2004). Codes used to describe saturated/unsaturated flow in pavement sections include HYDRUS-2D (Apul et al., 2004; Gardner et al., 2002; Simunek and Hansson., 2004), VS2DHI (Stormont and Zhou, 2004), and TOUGH2 (Stormont and Zhou, 2001). Simulation results indicate that these codes are capable of simulating the complex behavior of unsaturated flow within pavement sections. However, matching experimental data is difficult, and requires multiple adjustments of input data to produce a reasonable match. Some modeling issues particularly important to pavement drainage include determining the appropriate material properties for relatively coarse-grained soils and geosynthetics, and flow at the onset of saturation such as initiation of water flow into an edgedrain pipe. Before these codes can be used to design GCBD systems, they need to be validated against a robust set of experimental data. The MnROAD field test will provide these data.

Work Plan

The design tool for predicting GCBD drainage efficiency will be built around an unsaturated flow software program. At the most basic level this program must be capable of handling transient, two-dimensional, saturated/unsaturated flow with relatively sophisticated models of near-surface processes that utilize climatic data as input. In addition, the simulation program should have the ability to utilize a number of different pedo-transfer functions and empirical models for describing the moisture characteristic curve and unsaturated hydraulic conductivity function. Advanced capabilities that are desirable in terms of describing pavement drainage include water vapor transport; heat transport; hysteresis in the moisture characteristic curve; inverse solution modeling; and three-dimensional capability.

The HYDRUS-2D code has been selected for use in the project based on program capabilities (those described above); program availability, cost and user support; program documentation; ease of use (e.g., pre- and post-processor); and previous use for pavement drainage.

The as-built geometry and material properties of each layer will be utilized to create a detailed HYDRUS-2D model of the test section. Initial unsaturated hydraulic properties will be assigned to each material based on prior laboratory and field tests. Model calibration will be accomplished by comparing simulation results to measured field data of drainage and moisture movement obtained from the MnROAD test section. Initial conditions (moisture contents and temperatures of the sub-surface layers) and measured climate conditions will be used as input to the simulations. Based on previous experience with modeling of pavement sections, we anticipate that numerous iterations will be required before an optimal match between measured and simulated response is found.

The calibrated model will be used to investigate the impact of design parameters on GCBD performance. In this way, the numerical simulation model will serve as a design tool that allows site-specific conditions to be used in the design procedure. The model will permit the following parameters to be varied:

- Climate – temperature, humidity, precipitation, wind speed
- Pavement geometry – layer thickness, slopes, lane widths
- Material properties – hydraulic properties
- Source of water – pavement, pavement cracks, shoulder cracks, shoulder, upward moving water

The principal output from the model will be drainage quantity and water content within the pavement section, both with and without the GCBD.

Outcomes from this stage

A design tool for incorporating GCBDs into pavement design will be produced at the conclusion of Stage 3. This design tool will be based on simulations with an unsaturated flow code, and will be calibrated with the MnROAD field data. The calibrated design tool will be used to produce guidance for applications with different climate, materials properties and pavement sections.

Schedule and approximate budget

This stage will begin approximately 2 months after initiating the collection of field data at MnROAD and will conclude at end of the project in December 2006. The budget includes developing and calibrating the design tool, and applying it to different conditions. Costs are approximate.

Table 4 – Stage 3 activities, lead project personnel and approximate costs.

Activity	Lead project personnel	Budget (approximate)
Develop model of field test	Stormont	$15,000
Calibrate model	Stormont	$10,000
Use calibrated model to develop design guidance	Henry	$30,000
TOTAL FOR STAGE		**$55,000**

References

Apul, D., T. Eighmy, K. Gardner, E. Linder, T. Frizzell, and R. Roberson, "Two dimensional modeling of unsaturated water movement and contaminant transport in roads," Presented at the 2004 International Workshop on Water Movement and Reactive Transport Modeling in Roads, February 21-24, Portsmouth, NH.

Bendana, J., W. Yang, D. McAuliffe, J. Lu (1994)"Interpreting Data From the Falling-Weight Deflectometer," FHWA Research Report 160. Engineering Research and Development Bureau, New York State Department of Transportation.

Birgisson, B. and Roberson, R. (2000). "Drainage of Pavement Base Material: Design and Construction Issues." *Transp. Res. Rec. 1709*, TRB, National Research Council, Washington, D.C., 11-18.

Christopher, B.R. and V.C. McGuffey (1997). *NCHRP Synthesis of Highway Practice 239: Pavement Subsurface Drainage Systems.* TRB, National Research Council, Washington, D.C.

Gardner, K., Mercier, Y., Roberson, R.L., Apul, D.S. and Eighmy, T. (2002). "Using HYDRUS2D as an Innovative Tool to Study Water Movement in Pavement Systems." Paper 02-3702, *Proc. Annu. Meet. Transp. Res. Board*, TRB, National Research Council, Washington, D.C.

Hall, K.T. and C.E. Correa (2003). "Effects of Subsurface Drainage on Performance of Asphalt and Concrete Pavements," NCHRP Report 499. TRB, National Research Council, Washington, D.C.

Henry, K.S.; J. Olson, S. Farrington, C. Benda and J. Lens (in review). "Thaw Weakening Mitigation of Unpaved Roads in Vermont," submitted for consideration to Transportation Research Board 2005 Annual Meeting (Paper Number 05-1779).

Henry, K.S.; J.C. Stormont, L.A. Barna, R.D. Ramos (2002) "Geocomposite capillary barrier drain for unsaturated drainage of pavements," in Proceedings, 7th International Conference on Geosynthetics, Delmas, Gourc & Girard, eds., Swets & Zeitlinger, Lisse, pp. 877-880.

Henry, K.S. and J.C. Stormont (2002) "Geocomposite barrier drain for limiting moisture changes in pavement subgrades and base courses," Final Report for NCHRP-IDEA Project 68, The National Academies, Washington, D.C., 24p.

Simunek, J. and K. Hansson, "Models for simulating water flow and solute transport in subsurface: development, applications, and future plans," Presented at the 2004 International Workshop on Water Movement and Reactive Transport Modeling in Roads, February 21-24, Portsmouth, NH.

Stormont, J.C. and R. Ramos, (2004). "Characterization of a Fiberglass Geotextile for Unsaturated In-Plane Water Transport," *Geotechnical Testing Journal*, Vol. 27, No. 2, pp. 214-219.

Stormont, J.C. and S. Zhou, (2004) "Impact of unsaturated flow on pavement edgedrain performance," *ASCE Journal of Transportation Engineering*, in press.

Stormont, J.C., R. Ramos, and K.S. Henry, (2001) "A Geocomposite Capillary Barrier Drain with a Fiberglass Transport Layer," *Journal of the Transportation Research Board*, No. 1772, pp. 131-136.

Stormont, J.C., C. Ray, and T.M. Evans, (2001). "Transmissivity of a Nonwoven Geotextile under Suction," *Geotechnical Testing Journal*, Vol. 24, No. 2, pp. 164-171.

Stormont, J.C. and S. Zhou (2001) “Improving Pavement Sub-surface Drainage Systems by Considering Unsaturated Water Flow”, Cooperative agreement DTFH61-00-X-00099, report to the U.S. Department of Transportation, Federal Highway Administration.

Stormont, J.C. and T. Stockton, (2000) “Preventing positive pore water pressures with a geocomposite capillary barrier drain“, *Testing and Performance of Geosynthetics in Subsurface Drainage*, ASTM 1390, L.D. Suits, J. B. Goddard and J.S. Baldwin, Eds., American Society for Testing and Materials, West Conshohocken, PA, pp. 15-31.

Webster, S., D. Grau and T. Williams (1992) "Description and Application of Dual Mass Dynamic Cone Penetrometer," WES Instruction Report GL-92-3, May 1992.

Key Personnel and Facility

John Stormont

John Stormont is a Professor of Civil Engineering at the University of New Mexico where he teaches courses in unsaturated zone hydrology, soil mechanics and geotechnical engineering, waste containment technologies, geosynthetics, and civil engineering design. Dr. Stormont received his Ph.D. and MS degrees from the University of Arizona, and his BS from the University of Wisconsin. Dr. Stormont is actively working in the areas of saturated and unsaturated flow through soils and rock and geosynthetics, with applications to pavement drainage, near-surface water and energy balances, surface cover systems, groundwater contamination by on-site wastewater disposal, and soil drainage. He is also involved with projects on slope stability, soil erosion and acid mine drainage. He is co-author of the patent on the GCBD concept that is the subject of this proposal (with Dr. Henry). Dr. Stormont has published more than 40 peer-reviewed papers on geoenvironmental engineering topics. Prior to joining UNM in 1995, Dr. Stormont was a Senior Research Engineer at Sandia National Laboratories, where he conducted research on waste containment technologies and constitutive relationships for geomaterials. He is a registered Civil Engineer in the State of New Mexico.

His professional activities include membership in American Society of Civil Engineers; ASTM Committee D-35 on Geotextiles and related products; International Geotextile Society; International Association for Computer Methods and Advances in Geomechanics; North American Geotextile Society; Transportation Research Board, member of Committee on Engineering Behavior of Unsaturated Soils; Transportation Research Board, member of Committee on Geosynthetics; Transportation Research Board, member of Committee on Sub-surface Drainage.

Selected Relevant Publications (did not duplicate publications with Henry as first author):

Stormont, J.C. and S. Zhou, (accepted for publication) “Impact of unsaturated flow on pavement edgedrain performance,” *ASCE Journal of Transportation Engineering*.

Stormont, J.C. and R. Ramos, (2004). “Characterization of a Fiberglass Geotextile for Unsaturated In-Plane Water Transport,” *Geotechnical Testing Journal*, Vol. 27, No. 2, pp. 214-219.

Anderson, C.E. and J.C. Stormont, (2003) “Laboratory measurement of soil moisture at capillary potential greater than 1500 kPa,” Proceedings 2003 TRB Annual Meeting.

Stormont, J.C., R. Ramos, and K.S. Henry, (2001) “A Geocomposite Capillary Barrier Drain with a Fiberglass Transport Layer,” *Journal of the Transportation Research Board*, No. 1772, pp. 131-136.

Stormont, J.C., C. Ray, and T.M. Evans, (2001). “Transmissivity of a Nonwoven Geotextile under Suction,” *Geotechnical Testing Journal*, Vol. 24, No. 2, pp. 164-171.

Stormont, J.C. and T. Stockton, (2000) “Preventing positive pore water pressures with a geocomposite capillary barrier drain“, *Testing and Performance of Geosynthetics in Subsurface Drainage*, ASTM 1390, L.D. Suits, J. B. Goddard and J.S. Baldwin, Eds., American Society for Testing and Materials, West Conshohocken, PA, pp. 15-31.

Stormont, J.C. and C.E. Morris, (2000) "Characterization of Unsaturated Geotextiles," in *Advances in Unsaturated Geotechnics*, Geotechnical Special Publication 99, C.D. Shackelford, S.L. Houston, N-Y Chien, Eds., American Society of Civil Engineers, Reston, VA, pp. 153-164.

Morris, C. E. and J.C. Stormont, (2000) " Incorporating Near-Surface Processes in Modeling Moisture Movement in Soils," in *Advances in Unsaturated Geotechnics*, Geotechnical Special Publication 99, C.D. Shackelford, S.L. Houston, N-Y Chien, Eds., American Society of Civil Engineers, Reston, VA, pp. 529-542.

Stormont, J.C. and C.E. Anderson, (1999) Capillary Barrier Effect of Fine-over-coarse Soils, *Journal of Geotechnical and Geoenvironmental Engineering,* ASCE, Vol. 125, No. 8, pp. 641 - 648.

Stormont, J.C., K.. Henry, and T.M. Evans, (1997) Water retention functions of four non-woven polypropylene geotextiles, *Geosynthetics International,* Vol. 4, No. 6, pp. 661-672.

Stormont, J.C. and C.E. Morris, (1997) Unsaturated drainage layers for diverting infiltrating water, *Journal of Irrigation and Drainage Engineering,* ASCE, Vol. 123, No. 5, pp 364-367.

Karen Henry

Karen Henry is a Research Civil Engineer at the U.S. Army's Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. Dr. Henry earned her Ph.D. from the University of Washington with a geotechnical specialty, her M.S. degree from Northwestern University with a geotechnical specialty and her B.S. in Geological Engineering from Michigan Technological University. She performs experimental geotechnical and environmental engineering research. In addition to her past collaborative work with Professor Stormont on the GCBD, she has been the principal investigator on the use of geosynthetics as capillary barriers to reduce frost heave in soils and the use of geotextiles to reinforce weak soils. She is currently the principal investigator on the frost jacking of unexploded ordnance, the mixing of pavement bases and subgrades when thawing and unfrozen and on the use of geosynthetics to reinforce pavements. Dr. Henry is co-author of the patent on the GCBD concept that is the subject of this proposal (with Dr. Stormont). She has authored or co-authored 11 journal publications, two patents, and over 30 technical reports and conference papers.

Her professional activities include membership in American Society of Civil Engineers; International Geosynthetics Society; International Society of Soil Mechanics and Geotechnical Engineers; North American Geosynthetics Society (Past President); Society of Women Engineers: Senior Life member, past Section President, past Dartmouth Student Section Counselor; Transportation Research Board, Chair, Committee on Geosynthetics; Transportation Research Board, Member, Committee on Geosynthetics.

Selected Relevant Publications (did not duplicate publications with Stormont as first author):

Hayden, S.A., B.R. Christopher, K.S. Henry, D.N. Humphrey and C. Fetton (1999) "Effectiveness of geosynthetics for roadway construction in cold regions: Results of a multi-use test section," in Proceedings, Geosynthetics '99, Industrial Fabrics Association, St. Paul, MN, pp. 847-862.

Henry, K.S. and J.C. Stormont (2002)"Geocomposite barrier drain for limiting moisture changes in pavement subgrades and base courses," Final Report for NCHRP-IDEA Project 68, The National Academies, Washington, D.C., 24p.

Henry, K.S., J.C. Stormont, L.A. Barna, and R.D. Ramos, (2002) "Geocomposite capillary barrier drain for unsaturated drainage of pavements," *International Conference on Geosynthetics*, Nice, France.

Henry, K.S. and R.D. Holtz (2001) "Geocomposite capillary barriers to reduce frost heave in soil," Canadian Geotechnical Journal, Vol. 38, pp 678-694.

Henry, K.S., J.C. Stormont and R.D. Holtz (2000) "Geosynthetic capillary barriers in pavements," American Society of Civil Engineers, Geotechnical Special Publication. No. 94, pp. 350-364

Henry, K.S. (1998) "The use of geosynthetics to mitigate frost heave in soils," Ph.D. Dissertation, Civil Engineering Department, University of Washington, Seattle, 333 p.

Henry, K.S. and S. Patton (1998) "Measurement of the contact angle of water on geotextile fibers," ASTM Geotechnical Testing Journal, Vol. 21, No. 1, pp. 11-17.
Henry, K.S. (1995) "The use of geosynthetic capillary barriers to reduce moisture migration in soils," Technical Note, Geosynthetics International, Vol. 2, No. 5, pp. 883-888.

<u>Ruth Roberson</u>

Since 1997, Ms. Roberson has been a Research Scientist in the Minnesota Department of Transportation's Mechanistic-Empirical Design group where she conducts and manages research projects related to unsaturated soil mechanics, finite element modeling of subsurface flow patterns, pavement drainage and subsurface moisture conditions, and environmental instrumentation. Prior to working at MnDOT, Ms. Roberson spent 5 years at the University of Minnesota in the Soil Science Department working in agricultural and environmental research. Her time at the University was spent working primarily in the area of microclimate instrumentation. Ms. Roberson received her B.S. in Science in Agriculture with an emphasis in Soil Science, and is currently a graduate student in soil physics at the University of Minnesota.

Ms. Roberson's professional activities include membership in Soil Science Society of America; Transportation Research Board, member of Committee on Engineering Behavior of Unsaturated Soils; Transportation Research Board, member of Committee on Sub-surface Drainage; MnDOT Drainage Committee, Chair.

Selected Relevant Publications:

Roberson, R., J. Siekmeier, "Measuring Water Table Elevations Within Pavement Systems using Time Domain Reflectometry", Proceedings of TDR Symposium and Workshop, Northwestern University, Evanston, IL, September 5-7. 2001.
Roberson, R., J. Siekmeier, "Determining Frost Depth in Pavement Systems Using a Multi-Segment Time Domain Reflectometry Probe", Proceedings of TDR Symposium and Workshop, Northwestern University, Evanston, IL, September 5-7. 2001.
Birgisson B., R. Roberson, "Drainage of Pavement Base Material: Design and Construction Issues", Transportation Research Record No. 1709, Transportation Research Board, Washington D.C. 2000.
Roberson, R., J. Siekmeier, "Using a Multisegment Time Domain Reflectometry Probe to Determine Frost Depth in Pavement Systems", Transportation Research Record No. 1709 pp. 108-113, Transportation Research Board, Washington D.C. 2000.
Roberson R., B. Birgisson, "Evaluation of Water Flow through Pavement Systems", Proceedings of PIARC International Symposium on Subdrainage in Roadway Pavements and Subgrades, November 11-13. 1998.
Roberson, R. L. and C.F. Reece, "Comparison of Heat Dissipation Sensor, Tensiometer, and Thermocouple Psychrometer Response to Changing Soil Moisture Conditions", Poster/Abstract 85th Annual Meeting Soil Science Society of America. 1993.
Roberson, R. L. and C.F. Reece, "Water Potential Accuracy Determined by Heat Dissipation Sensor", Poster/Abstract 84th Annual Meeting Soil Science Society of America. 1992.

<u>Facilities</u>

This project will utilize the existing MnROAD test facility. The Minnesota Department of Transportation constructed the Minnesota Road Research Project (MnROAD) between 1990-1994. The MnROAD site is located 40 miles northwest of Minneapolis/St. Paul and is an extensive pavement research facility consisting of two separate roadway segments containing 51, 500-foot pavement test sections. The 3 ½-mile Mainline Test Roadway (Mainline) is part of westbound interstate 94 and contains 31 test sections and carries an average of 20,000 vehicles daily. Parallel and adjacent to the Mainline is a Low Volume Roadway (LVR) that is a 2 ½-mile-closed loop that contains the remaining 19 test sections. Traffic on the LVR is restricted to a MnROAD operated 18 wheel, 5-axle, tractor/trailer with two different loading configurations of 102kips and 80kips. Subgrade, aggregate base, and surface materials, as well as geometric design methods vary among test sections. Daily information is gathered via an automated data collection system that monitors more than 4500 mechanical and environmental sensors.

A 3.5-mile mainline interstate roadway carrying "live" traffic averaging 26,400 vehicles a day.

A 2.5-mile closed-loop low-volume roadway carrying a controlled 5-axle tractor-semi-trailer to simulated conditions of rural roads.

The two road segments comprise 51-instrumented concrete and asphalt pavement test sections representing a broad range of materials and designs that can be utilized for both pavement design research. Data collected from these test sections enable researchers to:

- Rapidly evaluate the potential performance of new designs and materials under real-life conditions.
- Examine the effects of environmental conditions, traffic loads and volumes, and innovative construction techniques and materials on pavement performance.
- Design customized experiments for both interstate and low-volume roads with the help of experienced MnROAD staff and on-site equipment to support unique researcher needs.
- Perform pavement testing in a completely safe work zone without disrupting the driving public because of MnROAD's unique parallel roadway for traffic diversion.
- Validate current and new pavement design procedures over a broad range of inputs.

In addition to MnROAD, the laboratory facilities of the University of New Mexico and the Cold Regions Research and Engineering Lab (CRREL) are available for this project. The Civil Engineering Department of the University of New Mexico has developed laboratory facilities that permit hydraulic characterization of both saturated and unsaturated soils and geosynthetics. This laboratory includes equipment for measuring moisture characteristic curves and unsaturated hydraulic conductivity (transmissivity) of geotextiles.

The Cold Regions Research and Engineering Lab (CRREL) is a facility of the U.S. Army Corps of Engineers that addresses the problems and opportunities unique to the world's cold regions. CRREL has an exceptional support staff that enables cold-regions related experimental programs to be conducted in the laboratory and field. The main laboratory includes a soils laboratory, machine shop and an electronics laboratory, all of which would be available as required for the proposed work. The electronics laboratory has considerable expertise in monitoring soil temperatures and automating data collection (e.g., from tensiometers).

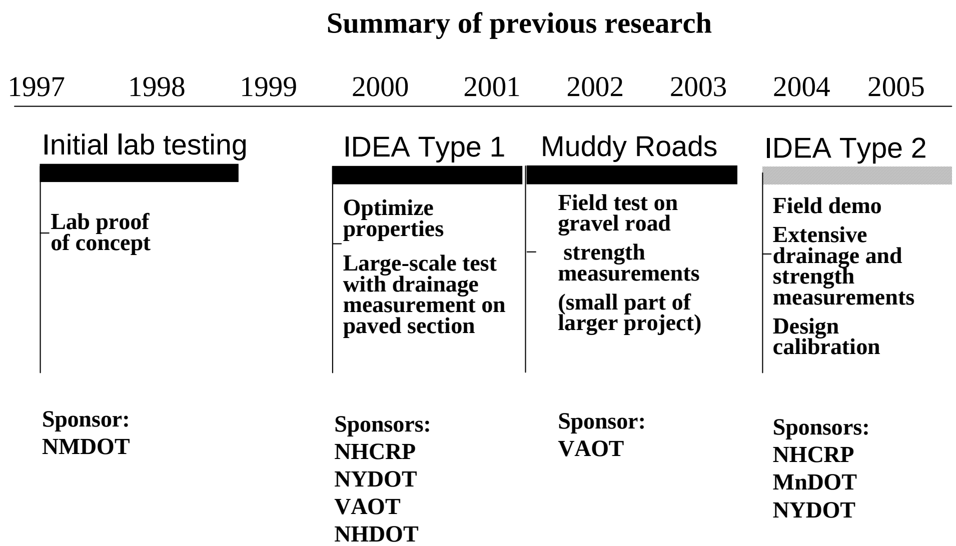


Figure 7 – Summary of previous research related to pavement drainage applications of GCBD technology.

IDEA Project 68 (PIs: Stormont and Henry)

The project was conducted in two stages. The objective of Stage 1 was to select the best possible transport layer for a GCBD system from available materials. In Stage 2, water movement and drainage within a full-scale pavement section with and without a GCBD system was evaluated. State transportation agencies from New York, Vermont and New Hampshire were involved in the planning and conduct of the research program via a pooled fund study.

Stage 1 – Initial evaluation of the GCBD concept indicated that drainage effectiveness is closely related to the unsaturated hydraulic properties of the transport layer. In particular, the transport layer should be transmissive under as wide range of suctions as possible while having a reasonable expectation for longevity in a sub-surface environment. Numerous candidate geotextiles were evaluated in a series of tests, including capillary rise, moisture retention function measurements, siphoning and transmissivity under suction. These test results reveal some geotextiles fabricated non-conventional materials such as fiberglass have a substantially greater ability to drain water under suction compared to conventional geotextiles fabricated from polypropylene and polyester. From these results, a multifilament, woven fiberglass geotextile denoted as TGLASS was selected as the best available material for a transport layer.

To confirm the expected performance of the TGLASS material as a transport layer, a GCBD with a TGLASS transport layer was placed between a subgrade and base course in a 3-m long sloped test device used to measure lateral drainage. Water was infiltrated during both constant rate infiltration and during a transient design storm event on the top of the base course, and drainage from the GCBD and the soil layers was collected. Measurements of soil suction were made within the soil layers. Test results are summarized in Figure 8. The GCBD was successful in draining sufficient water under suction to prevent positive pore water pressures from developing in the overlying base course and limit water movement into the underlying subgrade soil. The range of suctions over which the GCBD drained water from unsaturated soils was increased substantially over that of previous trial GCBDs that utilized polyester and polypropylene transport layers. These results imply that soils can be drained to much lower saturations with a GCBD that utilizes a TGLASS transport layer.

Stage 2 - In Stage 2 of the Type 1 IDEA project we tested 1) a control pavement with a separator between the base and subgrade and 2) a pavement with a GCBD placed between the base and subgrade. The tests were conducted in a large, waterproof box that contained a 1.3-m-long lane of pavement structure from the centerline, across an unpaved shoulder and through the bottom of a ditch (0.71 m of subgrade, 0.3 m of base gravel and 50 mm of asphalt). The asphalt contained a 2.5-mm-wide crack, 300-

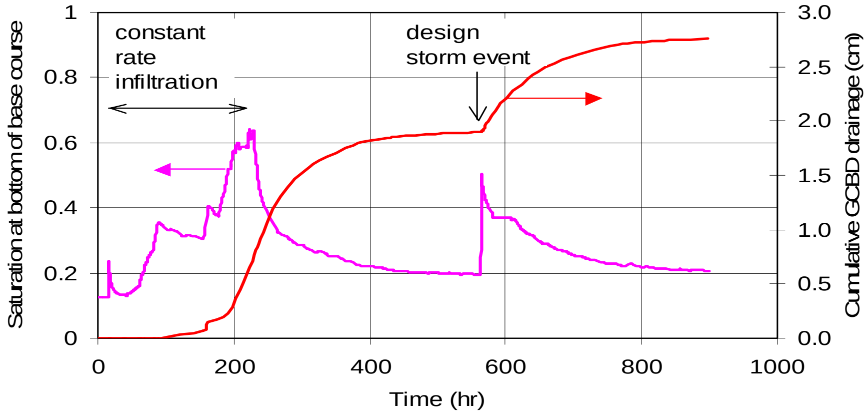


Figure 8 – Results from Stage 1 testing in Type 1 IDEA project that indicate that the base course does not saturate due to drainage provided by the GCBD.

mm in length that reached the top of the base. The box was placed at a 5% gradient from east to west and south to north and outflow was collected from the northwest corner. Water was applied to simulate storms that occur in the Northeastern United States. Outflow and soil moisture tension were monitored after each storm. At long-term steady-state infiltration rates of 0.1 to 0.15 mm hr^{-1}, the GCBD prevented all infiltrating water from reaching the subgrade (note that there was also surface runoff). Three tests simulated a four-year design storm in northern New England of 6 hours duration, and two tests were approximately equivalent to a 10-year design storm of 1 hour. The transport layer drained infiltrating water from overlying base at a minimum of 100 mm of suction head after water was applied. After one of the 6-hour storms, a small amount of water broke through into the subgrade; however, the GCBD recovered its function and protected the subgrade in a subsequent test that simulated a 1-hour storm.

Muddy Roads project – (PI: Henry) project ongoing.

Unpaved (gravel) roads in rural New England deteriorate during 'spring thaw,' or mud season every year. Construction with clean, non-frost-susceptible material helps prevent thaw weakening; however, most towns are constrained by available funding to purchase appropriate materials. To address this problem, a Vermont Agency of Transportation project was undertaken by the University of Vermont, the Cold Regions Research and Engineering Laboratory (CRREL), GeoDesign, Inc., and Applied Research Associates, Inc., to evaluate potential remedies for unpaved road deterioration during spring thaw. Candidate remedies were installed in test sections alternating with unimproved control sections along town-maintained roads in 2001. Two seasons of monitoring during mud season followed. CRREL oversaw test sections installed in Windsor,Vermont, including a GCBD test section. The GCBD was placed at a depth of 12 inches and sloped across the road at a 5% grade. The transport layer tied into a subsurface drain (about 18" deep), parallel to the road. California Bearing Ratio (CBR) determinations were calculated from the dynamic cone penetrometer values according to a US Army Corps of Engineers empirical correlation (Webster, et al., 1992) during two subsequent thaw seasons. The GCBD significantly increased the rate of recovery during thaw by keeping the 12 inches of overlying surface material drier than the road surface material in the two adjacent control sections (Fig. 9).

Geosynthetic unsaturated drainage system (PI: Stormont), project complete

Sponsored by the New Mexico Highway & Transportation Department. This project fostered development of the procedures and techniques required to test GCBD systems under unsaturated conditions. GCBD drain systems were tested in a 3-m-long test device, subjected to various infiltration rates and slopes. The tests proved that commercially available geosynthetics, when combined in a GCBD configuration, could readily drain water laterally while the adjacent soil remains unsaturated. Results show that system performance depends upon the slope, with increased lateral drainage occurring as the slope is increased. At slopes associated with pavement design (e.g., 2.5%), the GCBD system can successfully drain infiltration rates as great as $5x10^{-5}$ cm/sec over a distance of 3 m. The ultimate drainage length may be substantially further than the 3 m of our test device. The GCBD acts as a capillary break, and the amount of water that laterally drains in the upper soil layer depends on soil properties.

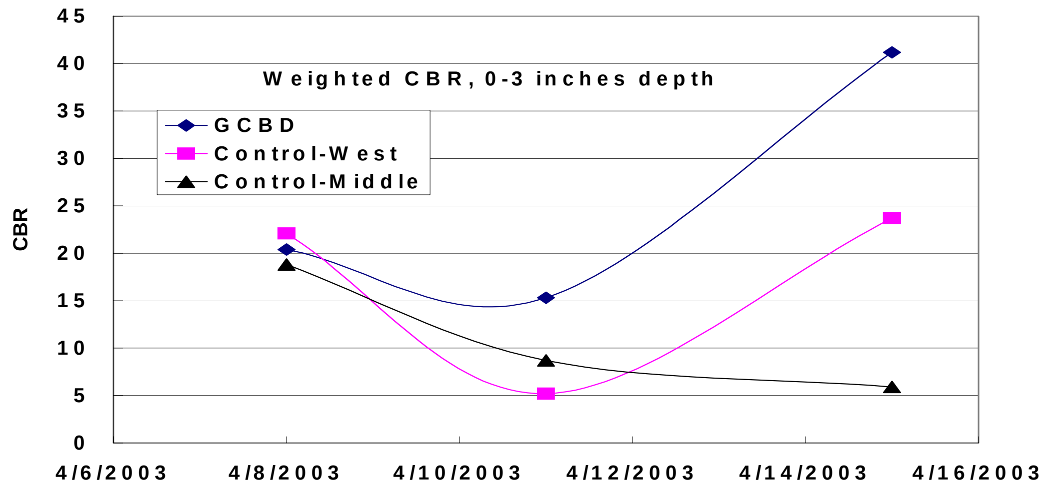


Figure 9 - Weighted California Bearing Ratio estimates for road surface material, 0 to 3 in. deep, for the GCBD test section and the two adjacent control sections. The surface of the road was thawed by 4/11/03.

Cost sharing and in-kind contributions

See attached letters of commitment and budget

MnDOT is participating by providing substantial in-kind resources. Notably, they are contributing the time of Ruth Roberson, a research scientist who has extensive experience with MnROAD field tests that focus on drainage. Her time along with some technician time on the project is valued at $50,000. MnDOT is also providing access and the infrastructure associated with the MnROAD facility. This contribution is difficult to quantify, but without it we could not conduct the project.

UNM and CRREL will provide equipment required for evaluating possible transport layer materials and conducting measurements on terminus details. As necessary, they will provide the facilities for measuring moisture retention functions and unsaturated hydraulic conductivity functions of soil and geotextiles.

The work described in this proposal is contingent upon additional funding provided by a pooled fund study that is being organized at the time of the proposal submission. New York, Minnesota and Michigan have already agreed to contribute to the pooled fund study pending approval of this proposal. These commitments represent about $100,000 of the $115,000 required budget. Please refer to the commitment letters appended to the proposal. Other states are presently considering whether to contribute to this effort, notably Wisconsin and New Hampshire. If funds in excess of the required amount become available, additional tests, data analyses and reports will be tailored to meet the interests of the funding agencies.

Reports and briefings

We will comply with guidelines set by the TRB IDEA staff for interim and final reports as well as participation in briefings. We will present research results in peer-reviewed journals and appropriate conferences for wide dissemination of these results. From the Type 1 IDEA project, we produced 2 journal papers and a conference paper in addition to the IDEA reports.