Relative Operational Performance of Geosynthetics Used as Subgrade Stabilization

Research Proposal

Submitted by

Eli Cuelho, P.E.
Research Engineer & Program Manager
Western Transportation Institute
College of Engineering
Montana State University

Steven Perkins, Ph.D., P.E.
Professor
Department of Civil Engineering
College of Engineering
Montana State University

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Research Programs
2701 Prospect Avenue
Helena, Montana 59620

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1 Problem Statement

State departments of transportation (DOTs) routinely use geosynthetics for subgrade stabilization. This construction practice involves placing an appropriately specified geosynthetic on a weak subgrade prior to placement of roadway subbase. The geosynthetic provides stabilization of the subgrade by increasing the load-carrying capacity of the system and maintaining separation between the soft subgrade and subbase materials. Subgrade stabilization allows for a firm construction platform to be built with less aggregate and less construction time as compared to construction without the stabilization geosynthetic. There is a general consensus concerning the effectiveness of geosynthetics in this application; however, there is a lack of understanding and agreement on the material's properties needed for performance. Those properties should be specified in order to ensure its beneficial use and to allow a broad range of products to be considered.

Many state DOTs currently allow both geogrids and geotextiles to be specified. As an example, at the Montana Department of Transportation (MDT), the current specification for a geogrid does not follow a standard specification; rather, it is written on a project-specific basis. It is typically written for a biaxial geogrid and specifies minimum values for the principal properties of ultimate tensile strength, strength at 2 percent strain, aperture opening size and junction strength. For a geotextile, a standard specification is used and is based on survivability properties and permittivity values.

In order to provide for the most economical geosynthetic selection while minimizing conflicts and promoting competitiveness, MDT and other states are interested in conducting a study to examine the performance of various geosynthetics for subgrade stabilization with the aim of relating this performance to material properties that can be incorporated into their standard specification to allow for a broad and economical use of geosynthetic products for a specific application.

2 Background

The Western Transportation Institute (WTI) recently completed a subgrade stabilization study for the MDT in 2009 (Cuelho and Perkins, 2009). This project was co-sponsored by NAUE GmbH & Co. KG (Germany), and used three of its products along with seven other geosynthetics to construct subgrade stabilization field test sections at the TRANSCEND research facility in Lewistown, MT. The test sections were constructed using a weak subgrade with a California Bearing Ratio (CBR) of 1.7 and with a relatively thin aggregate layer of 200 mm (8 in.). The aggregate layer was designed to carry fewer than 1000 traffic passes for sections without geosynthetics and more than 1000 traffic passes for sections with geosynthetics. The design was performed according to procedures contained in FHWA (1995) and checked against a more recent design method (Giroud and Han, 2004).

The test sections reached a terminal rut depth of 100 mm (4 in.) in less than 40 truck passes. The mode of failure of most test sections was a clear bearing capacity (shear) failure in the subgrade and involved tensile rupture of several geogrid products and pullout of one geotextile product. The results showed that several products that would not meet the previous MDT specification performed better than several other products that did meet that specification for this specific case. It was also shown that the ultimate tensile strength and tensile strength at 2 percent axial strain were relatively important material properties in determining how well the geosynthetics performed under conditions of rapid rut development. These properties were most important because of the large loads the geosynthetic was required to support, which approached, and in some cases exceeded, the ultimate tensile strength of the materials.

Subgrade stabilization for roadway construction generally requires that the subgrade-geosynthetic-base layer system reaches a stable condition. This condition is typically assessed by observing the deformation of the system under the single pass of a loaded vehicle and seeing that this deformation is minimal. Under stable conditions, bearing capacity failure of the subgrade has not occurred. In this operational condition, it is anticipated that other geosynthetic properties that might be more significant for conditions of smaller loads and deformations will be important for determining how well the material performs. The intention of the proposed research is to create these operational conditions in field test sections to determine which material properties are most responsible for showing good performance in subgrade stabilization applications.

3 Objective

The main objective of this project is to determine material properties of geosynthetics that affect in-field performance of geosynthetics used for subgrade stabilization, so that DOT personnel can objectively and confidently specify appropriate geosynthetics based on material properties and cost for a specific situation, while also allowing competition from different manufacturers. To accomplish this, test sections will be constructed at a controlled test site to investigate the relative benefit to an unpaved road of various geosynthetics available on the market. An artificial subgrade will be constructed to provide equivalent conditions for each test section; likewise the gravel surfacing along the entire test bed will be uniform to be able to make direct comparisons between geosynthetic products. Controlled traffic loading with frequent rut measurements will indicate performance benefits of each geosynthetic. Additionally, post-traffic examination will provide invaluable information regarding the performance and installation survivability of the geosynthetics. Further analysis will be conducted to illustrate cost savings by optimizing material properties that most influence the design and performance of these materials, thereby increasing the Department's knowledge base, confidence and efficiency as it seeks to update its specifications.

4 Business Case

The practice of using geosynthetics for subgrade stabilization saves money, time, and resources. In areas where excavation and replacement of inferior subsoils is not cost effective, soil stabilization using geosynthetics may provide a working platform so that the base course gravel layer can be properly constructed and overall rutting reduced. Historically, geotextiles were first used in these applications; however, geogrids have also been commonly used in more recent years. MDT has used both geotextiles and geogrids for subgrade stabilization in nearly all reconstruction projects, both large and small. MDT has previously supported this research because currently there is a lack of 1) a universally accepted standard design technique that incorporates non-proprietary material properties of geosynthetics when used for subgrade stabilization, and 2) agreement as to which geosynthetic properties are most relevant in these cases for purposes of specification development. This research was initiated to provide an understanding of which properties are most relevant for subgrade stabilization as MDT and other states seek to potentially update specifications to help ensure the most economical selection of a geosynthetic for a given application. This is particularly important since new geosynthetics and manufacturing processes are regularly introduced into the market, and having the ability to objectively select a geosynthetic product that meets the specifications at a competitive price will save both time and money.

This project will help to determine the most appropriate geosynthetic properties to be considered for the subgrade stabilization application. In addition, having this information readily available to planners and designers at state DOTs will give them the necessary information to objectively select an appropriate geosynthetic for a particular job. This will also help to avoid conflicts that may arise between the department and manufacturers/distributors when a particular geosynthetic is chosen over another. Avoiding these conflicts may prevent potential litigation, and save DOT personnel time and money.

5 Research Plan

The objectives of this research will be accomplished through a comprehensive program that includes laboratory tests on geosynthetics, as well as constructing, monitoring and analyzing full-scale field test sections at the TRANSCEND test facility. Information will be disseminated to the Technical Panel through detailed and timely quarterly reports, technical memoranda and regular project meetings. A final report and presentation will be delivered to summarize the results of this research. The major tasks associated with this work are detailed in the subsections that follow. Task 0 was added to describe project management activities.

Task 0 – Project Management

The Principal Investigators for this project will manage the project in terms of contractual compliance, budget and schedule, administrative tasks, and communications with the Technical

Panel. Mr. Eli Cuelho of WTI at Montana State University will serve as the Principal Investigator for the project. He will be the primary contact and assume the majority of the project management responsibilities. Dr. Steven Perkins will serve as Co-Principal Investigator for the project, and will be involved in project planning and analysis activities. Both Eli and Steven will be assisted by Dr. Barry Christopher, a consultant with over 30 years of experience working on geosynthetic-related projects.

Project management is important to ensure that the work proposed herein is completed on time, on budget and high quality. Management will generally be achieved through regular communication between the Principal Investigator, the MDT project manager, and research team members. The research team will submit brief and concise quarterly progress reports to describe accomplishments, status of the project and future plans. Major deliverables will follow MDT reporting requirements and formats and will first be sent to the Technical Panel for review and comment.

Task 1 – Material Characterization

Laboratory tests on the subgrade, base course and geosynthetics, as well as large-scale box tests conducted by a commercial testing laboratory, will be used to determine key material properties. Laboratory tests that will be used to characterize the materials used during this research project are discussed in greater detail below.

Subgrade – The artificial subgrade material will consist of a natural overburden material obtained from a nearby gravel pit. This soil classifies as an A-2-6 soil (according to the AASHTO classification system). The soil contains an appreciable amount of gravel and cobbles. Stones greater than 25 mm can be removed from this material by the supplier prior to delivering it to the test site; however, this screening process may not result in a soil with a different classification. Removing the larger stones from the subgrade will help better characterize the soil with the hand held vane shear and DCP measuring devices during and after construction, as well as save wear and tear on the tiller. The soil will be prepared to have a CBR strength of approximately 1.7 ±0.1 in the test pit.

During the previous project completed by Cuelho and Perkins (2009), CBR strength was correlated to shear strength (Figure 1) as determined by a hand-held vane shear device to facilitate field construction. The vane shear device is used during construction because: 1) it is simple to operate, 2) it provides a rapid assessment of in-place strength, and 3) it is more precise than other available devices. Laboratory testing will be done to validate the relationship between CBR and vane shear, as well as to document its index material properties. Further characterization of this material will also be accomplished through resilient modulus and repeated load triaxial tests by a commercial soil testing laboratory.

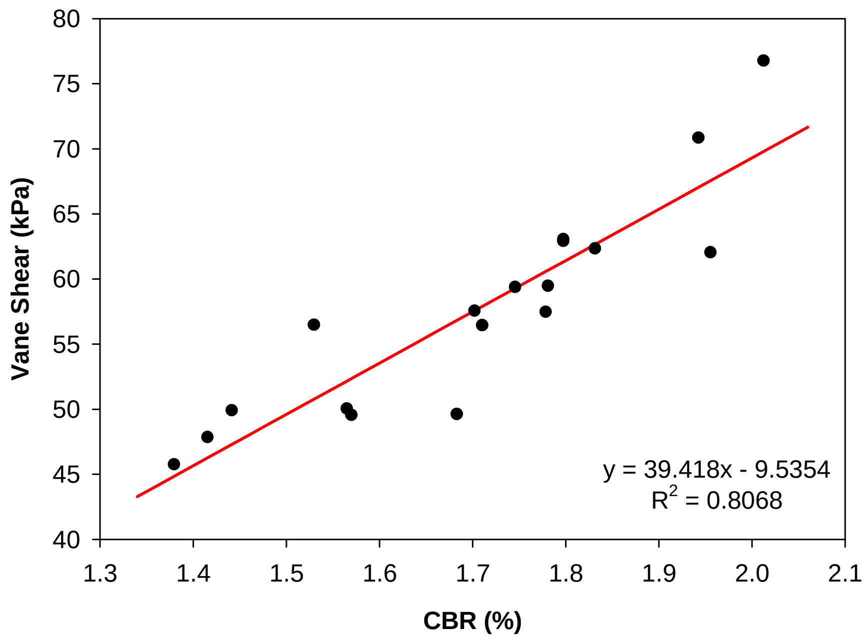


Figure 1: Relationship between CBR and vane shear device for the artificial subgrade.

Base Course Aggregate – The base course material used by Cuelho and Perkins (2009) consisted of a 1½-inch minus crushed gravel (Grade 6A according to MDT standard material specifications). According to MDT construction practices, a pit run material is typically used as subbase fill directly above the geosynthetic. The base aggregate to be used in this project will have the gradation and general material properties summarized in Table 1. Soil tests such as gradation, Atterberg limits and CBR will be conducted to verify these material properties of the base course aggregate prior to field construction. Further characterization of this material will also be accomplished through resilient modulus and repeated load triaxial tests by a commercial soil testing laboratory.

Geosynthetics – The geosynthetics selected for this study are listed in Table 2 and Table 3, which provide a basic description of the products and summarize the pertinent material properties of each product, respectively. The geosynthetics will be tested using a number of test procedures to determine their material properties under a variety of operating conditions. Samples from each of the geosynthetics will be taken to evaluate wide-width tensile strength (ASTM D4595 and ASTM D6637), cyclic tension stiffness (ASTM D7556), resilient interface shear stiffness (ASTM D7499), aperture stability modulus (GRI-GG2) and junction strength (GRI-GG2) in the two principal strength directions. Results from these tests will be used in the analysis to determine potential correlations to in-field behaviors as measured during trafficking. Information provided by the manufacturers about each roll will also be collected and documented.

Table 1: General Properties of the Base Course Aggregate

Sieve (US)	Sieve (mm)	Montana 5A (% pass.)
2-inch	**50.8**	100
1 1/2-inch	**38.1**	94-100
3/4-inch	**19**	70-88
3/8-inch	**9.5**	50-70
#4	**4.75**	34-58
#40	**0.425**	6-30
#200	**0.075**	0-8
Liquid limit		< 25
Plasticity index		< 6
Fractured faces (%)		≥ 50%
No. of fractured faces above #4 sieve		2+

Table 2: General Description of the Geosynthetics

Company	Product Name	Structure/Type	Polymer Type[a]	Aperture Size (in) MD	Aperture Size (in) XD
Colbond	Enkagrid Max30	laser-welded biaxial geogrid	PP	1.7	1.6
Huesker	Fornit 30	polymer-coated woven geogrid	PP	0.6	0.6
NAUE	Secugrid 30-30	vibratory-welded biaxial geogrid	PP	1.2	1.2
Propex	Geotex801	non-woven needle-punched geotextile	PP	#80[b]	
Syntec	Tenax MS 330	extruded multi-layer biaxial geogrid	PP	1.65	1.96
Synteen	SF-11	polymer-coated woven geogrid	PET	1.0	1.0
Synteen	SF-12	polymer-coated woven geogrid	PET	1.0	1.0
TenCate	Mirafi BXG-11	PVC-coated woven geogrid	PET	1.0	1.0
TenCate	Mirafi RS580i	woven geotextile	PP	#40[b]	
Tensar	BX1200	integrally-formed biaxial geogrid	PP	1.0	1.0
Tensar	TX140	integrally-formed triaxial geogrid	PP	1.6	1.6
Tensar	TX160	integrally-formed triaxial geogrid	PP	1.6	1.6

[a] PP = polypropylene, PET = polyester
[b] Apparent opening size (AOS) in standard US sieve size (ASTM D4751)

Table 3: Pertinent Material Properties of the Geosynthetics

Company	Product Name	Strength[a] @ 2% (lb/ft)		Strength[a] @ 5% (lb/ft)		Ultimate[a] Strength (lb/ft)		Junction Strength (lb/ft)	Flexural Rigidity (mg-cm)
		MD	XD	MD	XD	MD	XD		
Colbond	Enkagrid Max30	755	755	1576	1576	2329	2329	490	N/P
Huesker	Fornit 30	548	890	1370	1850	1850	2398	N/P	N/P
NAUE	Secugrid 30-30	821	821	1476	1476	2055	2055	617	500,000
Propex	Geotex801	N/A	N/A	N/A	N/A	205[b]		N/A	N/A
Syntec	Tenax MS 330	418	620	925	1340	1370	2100	1970	750,000
Synteen	SF-11	526	578	1042	792	2388	3870	600	N/P
Synteen	SF-12	526	797	1042	1367	2388	5268	720	N/P
TenCate	Mirafi BXG-11	501	501	920	920	2000	2000	481	N/P
TenCate	Mirafi RS580i	540	1920	1440	4380	4800	4800	N/A	N/A
Tensar	BX1200	412	618	810	1340	1300	1970	1450	750,000
Tensar	TX140	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P
Tensar	TX160	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P

[a] Manufacturers' minimum average roll values (MARV), ASTM D4595 and ASTM D6637
[b] Grab tensile strength in lbs at 50% elongation (ASTM D4632)
N/A = not applicable
N/P = not provided by manufacturer

Large Scale Box Roadway Tests – A single large-scale laboratory simulation will be conducted by a commercial laboratory using a 2 m x 2 m x 1.5 m test box that is capable of applying cyclic traffic loads to a rigid, 300 mm diameter plate resting on the aggregate base layer via a pneumatic loading device (Figure 2 and Figure 3). The test section will be constructed using the same base and subgrade materials used in the field test sections, which will be shipped by WTI staff to the testing laboratory. The base thickness will be selected to provide rutting performance meeting the standards for establishing a stable construction platform. Results from this test will be used to verify this level of performance prior to constructing field test sections and will provide assurance that field test sections perform to the level required. Any geosynthetic used in this test device will be representative of the materials used in the field test sections.

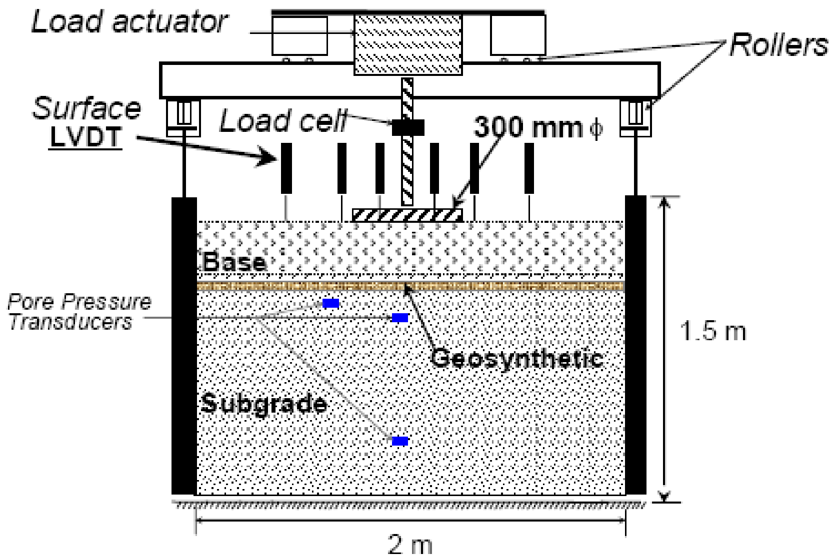


Figure 2: Schematic of unpaved road box test setup.

Figure 3: Photo of unpaved road box test setup.

Task 2 – Plan and Set up Monitoring Equipment

Five basic measurements are necessary in this research project to quantify and understand the behaviors of the geosynthetic in the field test sections during trafficking: 1) longitudinal rut depth of the gravel surface, 2) transverse rut profile of the gravel surface, 3) displacement of the geosynthetic in the transverse direction, 4) strain in the geosynthetic in the transverse direction, and 5) pore water pressure in the upper layer of the subgrade.

Displacement and pore pressure sensors will be mounted in a weatherproof box that is rigidly attached to the pavement outside of the test pit area. Laboratory experiments will be conducted to verify the behaviors of each of the sensors and to ensure that they will work properly when installed in the field. The data loggers and associated electronic equipment will be purchased and/or assembled prior to constructing the field test sections. The data loggers will be programmed to automatically record displacement, strain and pore-water pressure during the trafficking period, as well as take dynamic measurements of these same sensors during predetermined truck passes.

Rut – In the research project recently completed by Cuelho and Perkins (2009), longitudinal and transverse rut measurements were made using a digital level. This method was very accurate, yet time consuming (several hours between consecutive truck passes). A more complete and equally accurate set of measurements will be made using an alternate and more efficient method. Equipment needed to make these measurements will be designed, constructed and installed adjacent to the test site to be used during the trafficking period. This equipment will likely consist of a stiff metal frame that is mounted on rails or reference points placed at regular intervals along the track, to provide a quick reference to make several rut measurements in rapid succession. Automated devices, such as laser displacement sensors, LVDTs or extensometers are being considered for this apparatus to help speed the measurement process and facilitate a greater number of measurement points. Measurements made using this device will be periodically checked with the digital level to ensure accuracy. In the event that the rut measurement device becomes too difficult or expensive to construct, rut measurements will be made using the digital level, as was done during the first subgrade stabilization study conducted by Cuelho and Perkins (2009). Longitudinal rut measurements will be made at one-meter intervals along the length of each test section in both rut bowls; however, a 2- to 4-meter area between adjacent test sections will be ignored to avoid the transition zone. Transverse rut profiles will be taken at three locations in each test section, two of which correspond to the instrumented areas. Baseline measurements of the surface of the base course will be taken prior to trafficking. A suggested schedule for the remaining measurements is after truck passes 1, 2, 3, 5, 10, 15, 25, 50, 75, 100, 150, 200, 250, 300, 350, 400, 500, and every 100 passes until failure or 2,000 passes. Additional rut measurements may be necessary to capture early behaviors in sections that fail more rapidly.

Displacement – Transverse displacement of the geosynthetic will be measured in two separate locations along the length of each test section using three electronic displacement sensors (linearly variable displacement transducers, or LVDTs) at each location. These measurements will be made in the rut bowl location as shown in Figure 4. Figure 5 shows a plan view of the instrumentation layout in each test section (LVDT indicates a displacement measurement, PWP indicates a pore-water pressure measurement and SG indicates a bonded strain gage measurement). Displacement measurements will be facilitated through the use of lead wires that are attached to the geosynthetics using the methodology outlined in Cuelho et al. (2008). Both static and dynamic measures of displacement will be made during the trafficking phase.

Dynamic measurements will be taken at 100 Hz during several of the truck passes, more frequently during the beginning of the trafficking phase. Displacement measurements will primarily be used to determine lateral movements of the geosynthetic as traffic is applied; however, strain measurements will also be calculated using the three displacement sensors as illustrated in Figure 6.

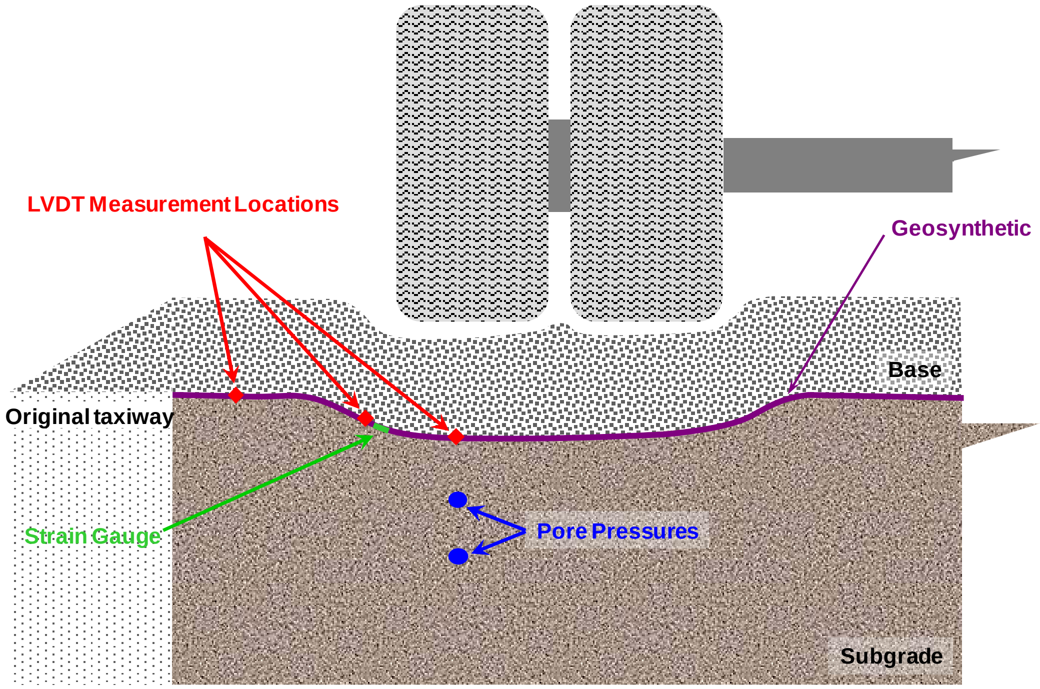


Figure 4: General location of sensors.

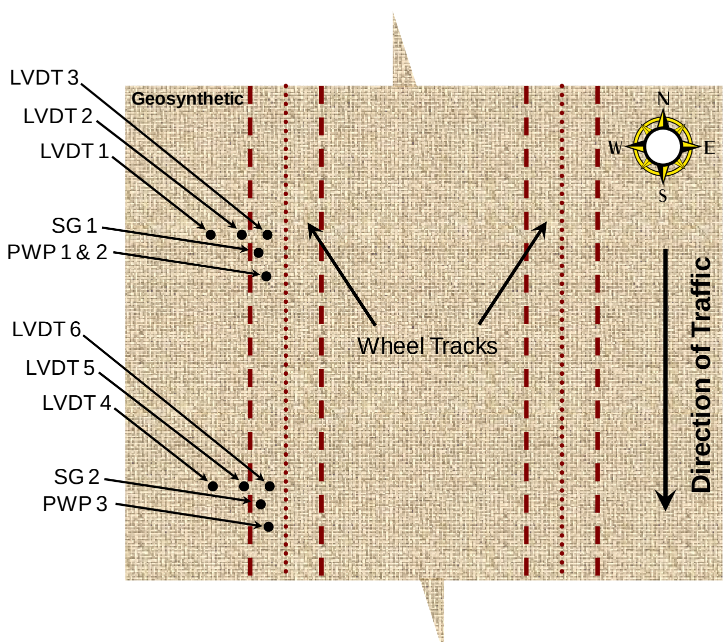


Figure 5: Plan view of instrumentation layout within each test section.

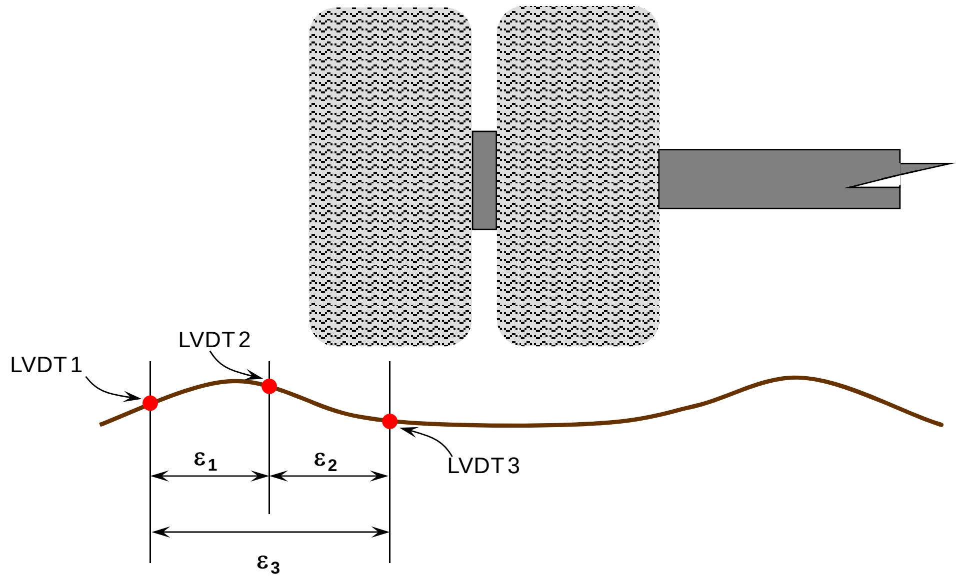


Figure 6: Illustration of strain calculation from displacement measurements.

Strain – Resistance strain gages will be carefully bonded to the surface of each of the geosynthetics in two locations within each test section. These sensors will be located near the displacement and pore-water pressure sensors, and will be mounted on the outer side of the rut bowl to capture the maximum strain in the geosynthetic induced by traffic loads.

Pore-Water Pressure – The moisture content within the subgrade will be sufficient to allow excess pore-water pressures to develop in the subgrade under vehicle loads; therefore, it is important to monitor pore pressures because laboratory tests have shown that pore pressure development can have a large effect on the performance of the system. Pore-water pressure measurements will be made in three locations in each of the test sections. Two measurements will be made at a depth of 15 cm below the surface of the subgrade and a third measurement will be made at a depth of 25 cm. These measurements will be made at two longitudinal locations in each test section near the displacement measurements (refer to Figure 5). The pore-water pressure sensors themselves will be housed in an enclosure along with the LVDTs and associated electronics. A rigid plastic tube with a ceramic porous stone will be used to extend the point of measurement from the wheel track to the sensor.

Task 3 – Plan and Construct Test Sections at TRANSCEND

The test sections will be constructed at TRANSCEND, a large-scale research facility in Lewistown, Montana. The facility comprises 230 acres, of which 64 acres contain abandoned runways and taxiways, which will provide an excellent foundation to support the research project under safe and controlled conditions. The test sections will be constructed on an existing taxiway to provide a convenient working platform during construction and trafficking. The artificial subgrade will be prepared and compacted within a trench that is approximately 1.0 meter deep, 4.7 meters wide and 260 meters long. The quality and consistency of the subgrade will be monitored frequently during construction to ensure uniform conditions are maintained along the entire length of the test area. Protective measures will be used to reduce wetting or drying of the subgrade from weather events such as rain or high winds.

Design of the experiment is based on a total of 16 test sections that are 4.7 m wide. Three control sections (i.e., no geosynthetic) will be constructed near the ends of the test plot as shown in Figure 7. Two of the control test sections (one on each end of the test site) will be constructed identically to the geosynthetic-stabilized test sections without the presence of the geosynthetic. An additional control test section will be built (on one end of the test site) with increased base course depth to attempt to match the performance of the geosynthetic-stabilized test sections. A duplicate geosynthetic-stabilized test section will be constructed with slightly weaker subgrade strength than the remaining test sections to better estimate the effect of subgrade strength on performance. Each test section containing geosynthetics will be 15 m long and the control and duplicate sections will be 20 m long for a total length of 260 meters. The exact location of the geosynthetic test sections will be determined at the time of construction. Construction activities basically include: excavation of the existing subgrade, placement of the new artificial subgrade, installation of the geosynthetics, setup and installation of the data acquisition system and instrumentation, and construction of the base course aggregate, which are described in greater detail below.

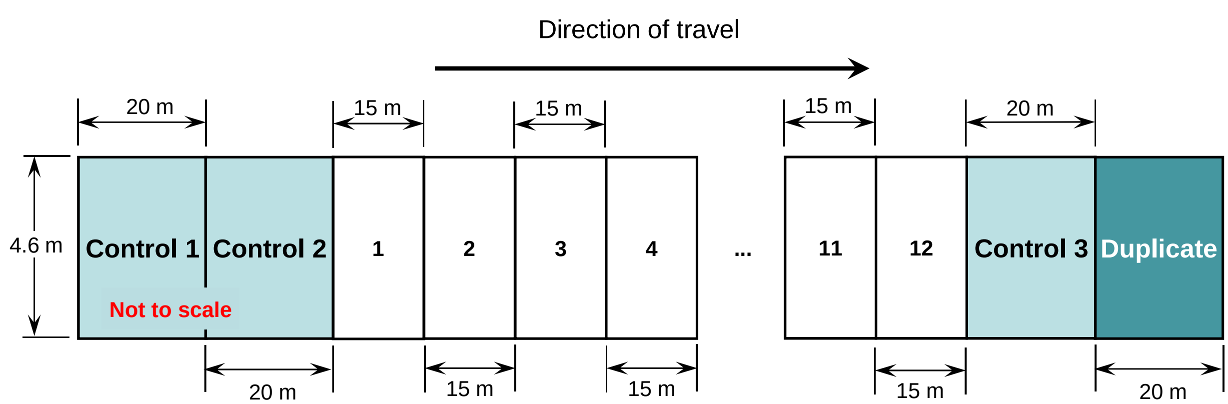


Figure 7: Basic layout of test sections.

There are six main steps involved in constructing the experiment at the TRANSCEND test site, as outlined below. A formal request for bid document will be created and sent to potential bidders to solicit construction bids. This document will detail what is required by the contractor for each step in the construction process. WTI staff will meet with potential bidders prior to the bid date to ensure that they are well acquainted with the job and its requirements. The construction contract will be awarded to the lowest qualified bidder. The construction steps are as follows:

1. **Excavate existing base course and artificial subgrade material from trench**—the existing test pit still contains the artificial subgrade from the previous project

(Cuelho and Perkins, 2009), which will be removed by the contractor and deposited on site.

2. **Widen the existing trench from 4 meters to 4.7 meters**—to further reduce the potential influence from the trench side walls during trafficking, the contractor will widen the test pit by 0.7 meters along its entire length.

3. **Install plastic liner in the trench**—the contractor will install and maintain a thin plastic membrane (6-mil) to line the entire length of the test pit to ensure a constant moisture content within the artificial subgrade throughout the duration of this research project.

4. **Prepare and place the artificial subgrade soil**—the artificial subgrade will be purchased from Casino Creek Concrete (Lewistown, MT) and delivered to the test site. The contractor will then prepare the subgrade to the specified moisture content and blend it for consistency. A front-end loader will be used to transport it from the stockpile to the test pit. A track-driven, skid-steer tractor will then distribute the artificial subgrade into thin lifts (15 to 20 cm deep), which will then be tilled using a large, tractor mounted roto-tiller. Moisture content will be the primary method used to ensure relatively uniform conditions in the artificial subgrade prior to compaction. A smooth-drum vibratory roller will then be used to compact the artificial subgrade. After compaction, the hand-held vane shear device will be used by WTI staff to measure in-place shear strength to ensure uniformity as well as document strength in each of the layers for future analysis. WTI staff will be present during the entire construction process to ensure consistent construction and quality of test sections. Areas that do not meet the required strength characteristics will be removed or modified by the contractor prior to constructing the next layer.

   The final layer of the artificial subgrade will be slightly crowned to prevent water buildup on its surface during the project, and plastic will be used to minimize moisture loss from the surface during construction. A Dynamic Cone Penetrometer (DCP), nuclear densometer, Lightweight Falling Deflectometer (LWD) and in-field CBR measurements will be used to characterize the strength of the artificial subgrade at multiple locations within each test section prior to installing the geosynthetics.

5. **Install pore-water pressure gauges, geosynthetics and displacement sensors**—three pore-water pressure gauges will be installed in each of the test sections by WTI staff as outlined in Task 2 above. Geosynthetics will be procured from individual manufacturers early in the project so that they can be cut to length and resistance strain gauges can be mounted on them. Geosynthetics will be installed by simply rolling them out in the direction of traffic and centering them on the test section regardless of their width. After the geosynthetics are installed, lead wires will be attached to facilitate lateral displacement measurements with

LVDTs. Rigid tubing will be used to protect lead wires during construction of the base course and trafficking. A stationary marker will be placed in each test section to monitor pullout of the geosynthetics in the cross-machine direction during trafficking.

6. **Construct the base course**—a base course aggregate typical of standard construction practices will be specified by the Technical Panel. The compacted depth of the base course will likely be between 36 and 46 cm (14 and 18 inches), and will depend on the recommendations from the Technical Panel, as well as the results from the big box tests (described in Task 1 above). The contractor will be responsible for delivering, preparing and constructing the base course on top of the geosynthetic stabilized test sections using lightweight equipment (track-driven, skid-steer tractor) from the side of the test site. The installation of the base course aggregate will be carefully monitored by WTI staff to prevent damage to the geosynthetics during construction. It is anticipated that the base course will be placed in two equal-depth layers. Final grading of the base course will also be done from the side using a road grader with an extended blade attachment, so that the test sections will be in a virgin state prior to trafficking. Similar to the artificial subgrade, a slight crown will be set in the surface of the base course so that water will not accumulate on the finished surface. A ramp will be made from the base course aggregate at both ends to allow the test vehicle to transition smoothly from the taxiway onto the test area. Longitudinal edges of the base course will generally follow a 2:1 slope. A smooth, single- or double-drum, vibratory roller will be used to compact the surface of the base course using an equal number of passes across the entire test site.

   Compaction of the base course aggregate will be carefully monitored during construction to evaluate the effect of lateral restraint and confinement from the geosynthetics during the compaction process. Multiple stiffness measurements using the LWD device will be made in all of the test sections to facilitate a direct comparison between test sections and the controls. It is anticipated that six measurements will be made in each test section in the first base course layer after the first pass of the compactor, and another six measurements after the final pass of the compactor in the first layer. Six more stiffness measurements will be made in each test section after the final pass of the compactor in the second (and final) layer of base course for a total of 18 LWD measurements in each test section. Once compacted, DCP and nuclear densometer measurements will be made, and a topographic survey will be taken to determine the depth of the base course across the entire test site.

Task 4 – Set up Instrumentation

Each data acquisition computer will be installed in a weatherproof box on site and powered through a solar panel and battery assembly. Eleven sensors will be installed in each geosynthetic test section (six LVDTs, three pore-water pressure gauges and two bonded strain gauges), and three pore-water pressure sensors will be installed in each control, for a total of 152 sensors. A laptop computer will be used to download, store and analyze data on site. A stationary datum will be installed in each test section to monitor movement of the edge of the geosynthetic in the transverse direction at a single location.

Task 5 – Trafficking and Monitoring

Trafficking will be accomplished using a fully loaded (~21,000 kg or 45 kips), tandem-axle dump truck. The bed of the dump truck will be loaded with concrete blocks to ensure similar applied loads on each tire throughout the duration of the trafficking period. Individual axles and wheels will be weighed using a calibrated scale. Lines will be painted on the gravel surface to properly position the truck on the test sections, in this case, centered over the geosynthetics. The truck will travel at approximately 15 kilometers per hour over the test sections. Passes over the test area will continue until each of the test sections reaches an average of 75 mm of rut as measured by changes in elevation over time, or until the truck has made 2000 passes. Rut measurements will be made using the apparatus briefly described in Task 2 above. Test sections that fail earlier will be repaired by adding additional base course aggregate and smoothing with lightweight construction equipment to facilitate continued trafficking of the remaining test sections.

Task 6 – Post-trafficking Forensic Investigations

Post-trafficking, forensic investigations will be conducted to evaluate damage to the geosynthetics during construction and from trafficking, as well as to re-evaluate pertinent soil strength characteristics. Intensive evaluations will take place in areas within each test section that have similar rutting (i.e., approximately 75 mm of rut). The base course will be removed from an area approximately 2 meters wide (in the direction of traffic) by the width of the test site (approximately 5 meters) to carefully expose the geosynthetic. Removal of the base course aggregate will be accomplished using a large vacuum truck and high-flow compressed air nozzle to minimize disturbance and damage to the geosynthetic during excavation. The geosynthetic will then be carefully removed from the area to analyze damage to junctions, rib integrity and material continuity. Samples of the extracted material will be removed to conduct monotonic tensile tests to evaluate changes in tensile strength during construction and trafficking, as well as to determine how much permanent strain was imparted in the material from construction and trafficking. Several DCP, vane shear, LWD, nuclear density, and in-field CBR measurements will be taken on the exposed subgrade surface within each test section. Additionally, the depth of the base course aggregate layer will be measured during these evaluations. The transverse rut profile of the base and subgrade will be measured on each side of the excavated area during these investigations to determine strain in the base course aggregate and characterize movement of the subgrade due to trafficking. Finally, the base and subgrade will be sampled from this area to comprehensively evaluate soil mixing between the subgrade and base course in the rutted areas, soil shear strength at various depths using the hand-held vane shear, and to facilitate a visual evaluation of the rutted area. Pullout of the geosynthetics will also be evaluated during these investigations using the stationary marker.

Task 7 – Data Analysis

Several types of data will be used to analyze the performance of each of the test sections, including:

- longitudinal and transverse rut measurements during trafficking,
- displacement of the geosynthetic in the rutted area,
- strain of the geosynthetic in the rutted area from displacement and strain gauges,
- pore-water pressure in the subgrade, as well as
- laboratory tests on geosynthetic, including:
  - cyclic tension,
  - resilient interface shear stiffness,
  - monotonic tensile stiffness and strength,
  - junction strength,
  - aperture stability modulus, and
  - index properties of the geotextiles (e.g., permittivity, apparent opening size).

The analysis of the respective performance of the test sections will be based largely on longitudinal rut depth as collected over time from the two outer wheel tracks in the rut bowl. These measurements will be averaged in each test section to be able to make direct comparisons of rutting performance. Rut behaviors will be normalized by depth of base course aggregate and subgrade strength. Quantitative comparisons between test sections will be made using a two sample t-test to evaluate the statistical significance of any differences in the mean rut depth over time.

A relatively comprehensive regression analysis will be conducted to correlate performance (based on mean rut depth) to various geosynthetic material and interaction properties (in this case, cyclic tension, resilient interface shear modulus, monotonic tensile stiffness and strength, junction stiffness and strength, and aperture stability modulus). During the previous project conducted by Cuelho and Perkins (2009), only tensile strength in the cross-machine direction was considered when trying to correlate material properties to field performance. The proposed analysis will provide a relatively complete assessment of which geosynthetic properties, or combination thereof, directly relate to their ability to reinforce or stabilize weak subgrades, thereby helping state DOTs modify their specifications to incorporate those material properties most directly related to field performance.

Strain and displacement will be used to characterize the global movement and strain within the geosynthetic during trafficking. This information will help discern reasons for potential differences in the rutting behavior between test sections. In addition, this information will be used to correlate with the strain and displacement levels used in the laboratory tests on the geosynthetics.

Finally, a cost-benefit analysis will be conducted as a comparison between the various geosynthetic-stabilized test sections and the control test sections. Cost information will be obtained from manufacturers and multiple departments of transportation. Benefit will be determined primarily from the rutting performance, but may also be dependent on improvements to compaction during the construction phase.

Task 8 – Reporting

A comprehensive final report that includes all data, analyses and recommendations will be written in conformance with MDT's standard research report format to thoroughly document the findings of this project. The report will be concise and include all pertinent information to aid state DOTs in adopting an efficient, effective, and reliable specification for geosynthetics used for subgrade stabilization. A draft report will be sent to MDT to be distributed to the Technical Panel for review and comment. The results of the project will also be disseminated, as appropriate, to the professional community through presentations at various conferences and/or through journal papers. A four-page "Project Summary Report" will be written and submitted to MDT near the end of the project to summarize the background, methodology, results and recommendations of this research. This summary report will be edited, published and distributed by MDT to be distributed to the Technical Panel for review and comment. After the final report is accepted, the Principal Investigator will formally present the methodology and findings of the project to all interested parties, including the Technical Panel and participating state representatives.

Five task reports will be written to summarize work associated with the following major activities.

- Task Report 1—Summarize construction plans prior to construction
- Task Report 2—Summarize construction activities prior to trafficking
- Task Report 3—Summarize trafficking and monitoring activities
- Task Report 4—Summarize post-trafficking forensic investigations
- Task Report 5—Summarize material characterization efforts

Quarterly progress reports will be submitted to provide updates on the administrative aspects of the project, such as progress regarding the schedule and budget.

6 Products

The products to be delivered during this project include the following items.

- Quarterly progress reports.
- Five tasks reports.
- A draft final report and executive summary describing the research methodology, findings, conclusions, and recommendations, followed by a final report addressing comments and suggestions from the Technical Panel.
- A four-page draft project summary report.
- An executive presentation to all interested parties and including the Technical Panel and participating state representatives, at the conclusion of the project.

7 Implementation

The results of this study will provide state DOTs with recommendations on geosynthetic material properties and values that are most significant in determining their effectiveness for subgrade stabilization. These recommendations will pertain to operational conditions where a stable construction platform is established over soft subgrade and is ready to accept structural pavement layers. Results from the previous study will be incorporated into these recommendations to provide minimal values of tensile strength to prevent tensile rupture in inadvertent or extreme loading events.

State DOTs will use these recommendations to potentially revise their current specifications for geosynthetics used for subgrade stabilization. Once the results of this study are available, it is anticipated that the DOTs can immediately implement these results into updated specifications if warranted.

8 Staffing

Mr. Eli Cuelho will be the Principal Investigator and Dr. Steven Perkins will be the co-Principal Investigator for this research project. As Principal Investigator, Mr. Cuelho will be the primary manager and sole point of contact with the MDT project manager. Both Principal Investigators will be responsible for ensuring that the objectives of the study are accomplished, executing the project tasks, and preparing the final report. Dr. Barry Christopher has over 30 years of experience working on geotechnical-related projects including road design using geosynthetics. He will be consulted throughout the duration of this project to ensure that the methodologies employed are appropriate and the project results are channeled into practice on a national level.

Several other staff members will be incorporated into various aspects of this project throughout its duration. Three such individuals include Mrs. Michelle Akin, a Research Associate; Mr. Jason Harwood, a Research Associate, and Mr. Keith Fortune, a Project Assistant. They will provide assistance in setting up the data acquisition equipment, conducting laboratory tests, installing instrumentation, and other miscellaneous construction activities. A qualified and experienced driver with a commercial license will be employed to operate the test truck during trafficking. Graduate and undergraduate students will also be employed to help with all aspects of the project.

The research team is well qualified, experienced and available to conduct this research, and, to the best of its ability, will deliver a quality finished product in a timely and efficient manner. The level of effort proposed for principal and professional members of the research team will not be changed without prior consent of the Technical Panel. The following paragraphs describe some of the qualifications and experience of key project personnel in addition to each person's role in this study. Additional information for key personnel can be found in Appendix A.

Mr. Eli Cuelho, P.E.—Principal Investigator

Mr. Eli Cuelho is a Research Engineer and the Program Manager of the Infrastructure Maintenance and Materials program area at WTI. Mr. Cuelho is a licensed professional engineer in the state of Montana and is currently involved with a number of research projects related to the design and maintenance of transportation infrastructure. He has over 12 years of experience on a variety of research topics including geotechnical engineering, geosynthetic design, pavement design and analysis, subgrade stabilization, cost-effectiveness and cost–benefit analyses, large-scale field tests and remote sensing and data acquisition equipment.

Geotechnical- and/or pavement-related research projects led by Eli Cuelho include:

- Field Investigation of Geosynthetics Used for Subgrade Stabilization—the objective of this project was to construct test sections in the field to investigate the relative benefit of various geosynthetics available on the market to an unpaved road built on a very weak subgrade.
- Developing a Standard Test Method for Measuring Geosynthetic-Soil Resilient Interface Shear Stiffness—the objective of this project was to develop a standard test method within ASTM to determine the interaction properties of geosynthetics that are embedded in soil and loaded under cyclic loads pertinent to transportation applications.
- Feasibility of Using a Gyratory Compactor to Determine Compaction Characteristics of Base Course Aggregates—the objective of this project was to explore the effectiveness of using a gyratory compactor to provide an accurate prediction of optimum in-place soil densities.
- Comparative Analysis of Coarse Surfacing Aggregates Using the Micro-Deval, L.A. Abrasion and Sulfate Soundness Tests—the objective of this project was to determine whether the Micro-Deval test can be used to replace the Sulfate Soundness test to accurately measure the durability of aggregates used in pavement.
- Preventive Maintenance Treatments: A Synthesis of Highway Practice—the objective of this project was to identify existing and emerging technologies that could be used to enhance or replace current pavement maintenance approaches used by the Montana Department of Transportation.
- Cost Effectiveness of Crack Sealing Materials and Techniques for Asphalt Pavements—the objective of this project was to determine the most economical and effective materials

and methods for sealing cracks in flexible pavements in Montana using field test sections and visual monitoring.

As the Principal Investigator, Mr. Cuelho will participate in and provide oversight for all the components of this research project. He will meet with the Technical Panel at the various times specified in the research plan and will write and review the technical memoranda and final report. Mr. Cuelho will be intimately involved in the construction, monitoring and analysis of the test sections to ensure that the project is executed with the highest quality.

Dr. Steven Perkins, P.E.—Co-Principal Investigator

Dr. Steven Perkins is a Professor in the Civil Engineering Department at Montana State University and has over 13 years of experience working on projects related to geosynthetics and, in particular, projects related to geosynthetic reinforcement of pavements. Dr. Perkins has been the Principal Investigator of 10 research projects focused on aspects of reinforced pavements ranging from the measurement of field performance of reinforced pavements to the development of design methods. In these projects, work components have included the development of material testing methods and the use of instrumentation for the measurement of material response. Dr. Perkins has written over 40 articles, reports and book chapters and has given over 50 presentations related to geosynthetics. Dr. Perkins has been involved in the preparation of several synthesis reports for NCHRP and AASHTO on research and practice of geosynthetics in pavements. He has assisted with the development and delivery of several short courses and workshops on pavement design with geosynthetics sponsored by industry and agency groups and delivered to practicing engineers and DOTs.

Dr. Perkins will be the Co-Principal Investigator of the project and will support the management needs of the project. Dr. Perkins will also be involved during the construction and monitoring of this project based on his related and extensive experience with full-scale test sections, and will be chiefly in charge of the analysis of the data from these field test sections.

Dr. Barry Christopher, P.E.

Barry R. Christopher has over 30 years of engineering experience in both paved and unpaved roadway design. As a project engineer with STS Consultants in Chicago, and currently as an independent geotechnical consultant in Atlanta, he has been involved in hundreds of commercial and transportation projects involving various aspects of roadway design and construction including planning and directing subsurface exploration programs, subgrade support design, unpaved and haul-road design, and flexible and/or rigid pavement design. Projects included new and reconstructed/rehabilitated roadways, runways, storage yards, warehouses, and parking facilities. He has worked closely with the U.S. Forest Service and the U.S. Army Corps of Engineers on the use of geosynthetics in unpaved roads for drainage, separation, subgrade stabilization, and aggregate reinforcement. As indicated in his resume, he has been involved in a number of instrumented, full scale laboratory and field test sections to fully evaluate the performance of these alternate techniques. He has also performed companion studies on lime and cement stabilized soils, and conducted mix designs for these and other chemical stabilization methods on a number of roadway projects. He has authored numerous technical papers on these subjects including six design manuals for FHWA, a textbook on geosynthetic engineering and three National Cooperative Highway Research Program syntheses including Pavement Subsurface Drainage Systems, Maintenance of Highway Edgedrains and Geosynthetic Reinforcements in Roadway Sections. He recently authored a section in the new FHWA geosynthetics manual on the use of geosynthetics in chip seal applications, a new method that has shown the potential for significant performance improvement of low-volume roads. He is a National Highway Institute certified instructor, teaching a number of training courses for FHWA including Geosynthetics Engineering, Drainage in Pavements, and Geotechnical Aspects of Pavements. He co-authored the recent FHWA design manual on geotechnical aspects of pavements, which contains a description of development of paved and unpaved roadway design through the current mechanistic–empirical design approach (based on AASHTO design methodologies). In addition to providing design guidance using both empirical and mechanistic–empirical methods, the manual also covers subsurface exploration requirements (from a risk-based approach), development of design parameters, design and construction details, and quality control/quality assurance requirements (including an introduction to performance evaluation methods). He has also been involved in two FHWA-sponsored research teams to evaluate and develop mechanistic–empirical design models for geosynthetic reinforced pavements. Much of his current work is on extending these models to unpaved roadway applications. He has worked on an initial Strategic Highway Research Program pavement subsurface evaluation committee and is currently working on the SHRP II R02 Geotechnical Solutions initiative as a team member and co-principal investigator for the element on stabilization of pavement working platforms.

Dr. Christopher will provide advice during the construction, monitoring and analysis phases of this project to ensure that they provide high quality, informative, useful and thorough information to the intended audience.

Mrs. Michelle Akin, P.E.

Mrs. Michelle Akin is a Research Associate at WTI and has been conducting civil engineering research related to infrastructure maintenance and materials since completing a master's degree in civil engineering in 2006. She has compiled synthesis reports and literature reviews related to pavement maintenance, subgrade evaluation, sensors to monitor bridges, and winter maintenance practices. She has extensive laboratory experience testing pavement and geotechnical materials and field experience setting up data acquisition systems, collecting soil samples, and monitoring construction activities. She is also certified by MDT to operate nuclear gauges to assess in-place density of aggregates.

Mrs. Akin will help lead the materials characterization work, assist with data collection in the field and be chiefly responsible for setting up and maintaining the data acquisition equipment. She will also assist the graduate and undergraduate students in analyzing the data from laboratory and field tests.

Mr. Jason Harwood, P.E.

Mr. Jason Harwood is a Research Associate at WTI with a master's degree in Mechanical Engineering from Montana State University. Over the past four years, he has helped design, construct, and use the snowmaking system at TRANSCEND, a cold region research facility in Lewistown, Montana. He is also working to develop an Accelerated Pavement Tester for pavement rehabilitation projects. Additionally, Mr. Harwood assists with many other research activities including geosynthetic testing, concrete testing, data acquisition system setup, field testing at TRANSCEND, and laboratory equipment design.

Mr. Harwood will assist with the materials characterization work, data collection in the field, and be chiefly responsible for designing and setting up a device to efficiently assess longitudinal and transverse rut profile. His degree in mechanical engineering and his technical experience make him uniquely qualified to conduct this work.

Mr. Keith Fortune

Mr. Keith Fortune is a Project Assistant at WTI for the Infrastructure Maintenance and Materials Program, Winter Maintenance and Effects Program, and the Corrosion and Sustainable Infrastructure Laboratory. He brings eleven years of professional experience in the fields of land rehabilitation, remedial investigations and processes for environmental sites, large-scale project supervision, and laboratory and field work. Mr. Fortune will provide support for this project in the field by collecting data and installing the monitoring system.

Graduate and Undergraduate Students

The research team will be supported by qualified graduate and undergraduate research assistants, who will work part-time on this project throughout its duration. The students will assist with conducting laboratory tests, in-field monitoring of the test sections, organizing and analyzing the data, and helping to synthesize information into the final report.

Research Team Hours and Availability

It is anticipated that the proposed work associated with this research project will take 5,556 person hours. The number of hours committed to the project by each member of the research team during this time period is shown in Table 4. Key personnel assigned to accomplish the work associated with this project are available throughout the duration of this project. Barry Christopher of Christopher Consultants, a sub-consultant to the project, is available to help for the time commitment he has been assigned. In the event that the level of effort proposed for any member of the research team requires significant modification, written consent will be sought from the Technical Panel to justify and approve this change.

Task	**Eli Cuelho** — Principal Investigator	**Steven Perkins** — Co-Principal Investigator	**Barry Christopher** — Consultant/Project Advisor	**Michelle Akin** — Instrumentation & Data Collection	**Jason Harwood** — Material Char. & Instrumentation	**Keith Fortune** — Field Work	**Commercial Driver** — Trafficking Test Sections	**Graduate Student** — Lab/Field Work & Analysis	**Undergraduate Student** — Lab/Field Work	**Undergraduate Student** — Lab/Field Work	**Support Staff**	**Total**
0 - Project management	240	40	8	0	0	0	0	0	0	0	16	304
1 - Material characterization	32	20	0	16	40	0	0	160	346	0	0	614
2 - Setup monitoring equipment	48	8	0	120	160	40	0	346	40	40	0	802
3 - Planning & construction	160	40	24	40	40	128	0	160	184	40	8	824
4 - Install instrumentation	60	0	0	60	80	40	0	80	80	40	0	440
5 - Trafficking & data collection	40	20	0	224	0	0	224	224	0	0	0	732
6 - Forensic investigations	40	40	0	0	0	40	0	160	24	40	0	344
7 - Data analysis	136	100	20	16	0	0	0	320	0	0	0	592
8 - Reporting	384	80	8	8	0	0	0	400	0	0	24	904
Total	**1140**	**348**	**60**	**484**	**320**	**248**	**224**	**1850**	**674**	**160**	**48**	**5556**

Table 4: Summary of Person Hours by Task

9 Facilities

The Western Transportation Institute (WTI) is the nation's largest transportation institute focusing on rural transportation issues and is designated as a U.S. Department of Transportation University Transportation Center. The Institute was established in 1994 by the Montana and California departments of transportation, in cooperation with Montana State University–Bozeman. WTI is part of the College of Engineering at MSU and has an 80-person multidisciplinary research staff of professionals, students, and associated faculty from the fields of engineering (civil/mechanical/industrial/electrical), computer science, psychology, fish and wildlife, business, biology and economics.

WTI has an annual budget of approximately $8 million, which is obtained from a diverse sponsor base including 26 state departments of transportation, the U.S. Department of Transportation, and other federal agencies such as the National Science Foundation, Department of Homeland Security, Transportation Research Board and the National Park Service. WTI also receives funding from private foundations, Parks Canada and several companies.

WTI integrates expertise from eight research areas: Infrastructure Maintenance and Materials, Road Ecology, Safety and Operations, Winter Maintenance and Effects, Systems Engineering

Development and Integration, Logistics and Freight Management, Mobility and Public Transportation, and Transportation Planning and Economics.

This research will be conducted within the Infrastructure Maintenance and Materials program area of which Eli Cuelho (the Principal Investigator for this project) is the program manager. The Infrastructure Maintenance and Materials program area at WTI conducts basic and applied research to address the immediate and long-term construction and maintenance needs of rural highway departments in the following areas:

- Materials—conduct research using new materials, such as geosynthetics or high performance concrete, to evaluate their benefit in new and rehabilitated highway structures.
- Maintenance—develop best management practices using cost–benefit analyses to help state highway departments select the most appropriate and cost-effective maintenance methods to extend the life of their facilities.
- Monitoring—test and evaluate instrumentation and remote sensing technologies to better monitor the condition of transportation infrastructure.

Additional information on WTI can be obtained from our web site at www.WesternTransportationInstitute.org.

Laboratories

WTI and the Civil Engineering Department at MSU have extensive laboratory facilities including Geotechnical, Aggregate Materials, Asphalt, Concrete, Geosynthetics, Environmental, Structural, and Subzero Research testing labs, as well as a large-scale outdoor research and testing facility (TRANSCEND – www.transcendlab.org). These laboratory facilities are used for both teaching and research purposes. The geotechnical and materials laboratories are fully equipped to conduct a wide range of tests on soils and aggregates using AASHTO and ASTM standard methodologies. The laboratories contain fully functional and up-to-date equipment to conduct a wide variety of tests, including:

- soil index testing (e.g., gradation, Atterberg limits, AASHTO and ASTM material classifications, etc.),
- specific gravity tests,
- L.A. Abrasion tests,
- gyratory compaction of asphalt and soil,
- small- and large-scale (12 in x 12 in) automated direct shear tests,
- computer-controlled consolidation testing,
- advanced triaxial testing,
- cyclic modulus testing of geosynthetics,
- x-ray computed tomographic (CT) scanning,
- environmentally controlled tests (accurate temperature control over a wide range, humidity control, UV radiation, etc.), and
- asphalt and concrete tests.

Equipment

Field equipment needed to accomplish the goals of this research will be purchased or obtained by WTI, as indicated below, including:

- excavation equipment to extract soil and/or dig test pits (rented),
- Dynamic Cone Penetrometer (purchased),
- Lightweight Falling Deflectometer (purchased),
- topographic surveying equipment (on-hand), and
- sample collection and storage equipment (purchased).

Information Services

The research team regularly conducts literature and information gathering through the Carnegie Research Level 1 Library (Renne Library) on the MSU campus. In addition to an extensive collection of printed material, the library subscribes to dozens of databases and hundreds of refereed journals in print and electronic format. Specific items not accessible through these sources can be located and retrieved by the Interlibrary Loan service, which is affiliated with other research libraries across the United States. Typical sources used to aid literature searches include: TRID (Transport Research International Documentation), E-Science Server, Transportation Research Board Research Records and Annual Meeting CD-ROMs, Google Scholar, Google, and Montana Local Technical Assistance Program library.

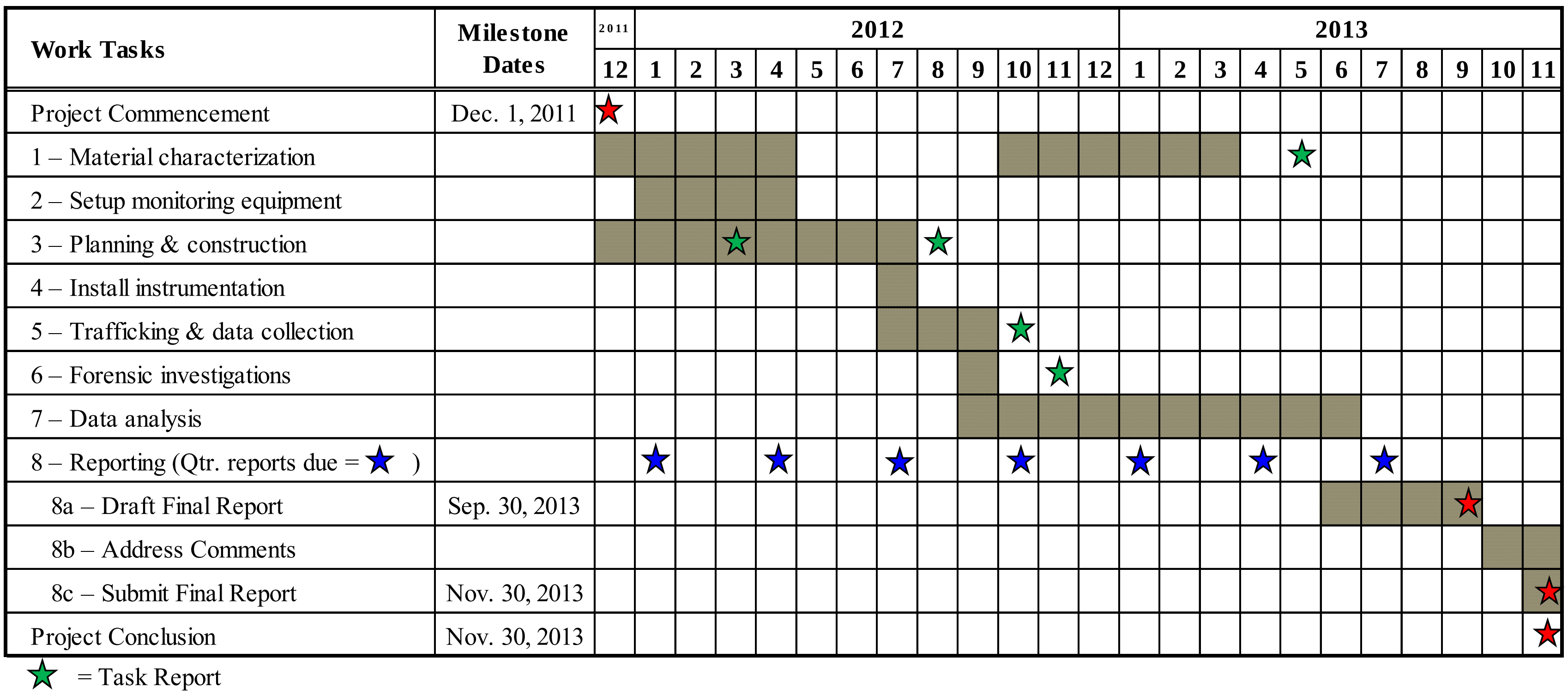
Administrative Services

The researchers at WTI are assisted by a highly qualified group of experienced support staff. Administrative staff members assist with budgeting, procurement, contracts, and accounting. Communications staff provides technical editing, layout, graphic design, and web page support. Information Technology staff maintains network servers and individual computers, software and hardware.

10 Schedule

The estimated project schedule is depicted in Table 5. The total proposed duration of the project is 24 months, with an estimated start date of December 1, 2011, and an estimated completion date of November 30, 2013. Significant time for planning is needed prior to construction in order to gain sufficient laboratory experience with the materials to design the test sections and data acquisition system. Construction is scheduled during the summer of 2012, and a draft of the final report is planned for the following year. A draft final report will be sent to the Technical Panel two months prior to the end date (by September 30, 2013) to provide sufficient time for review and revision. Task reports will summarize work associated with major activities and are shown in Table 5 as a green star. The data analysis task will be summarized in the final report. Quarterly reports will be sent to the Technical Panel during the months following the end of each quarter, as shown in Table 5.

Table 5: Project Schedule



11 Budget

The requested project budget is $581,726. Schedule, budget, and staffing plans are based on state and federal fiscal year proportioning, as shown in Table 6. Indirect costs are calculated based on a negotiated rate of 30 percent of salaries and benefits.

Table 6: Detailed Budget by State and Federal Fiscal Year

Budget Category	State Fiscal Year			Federal Fiscal Year		Total
	2012	2013	2014	2012	2013	
Salaries	$46,319	$77,620	$15,388	$69,942	$69,384	**$139,327**
Benefits	$11,625	$18,376	$3,872	$17,218	$16,655	**$33,873**
Subcontracts	$6,000	–	–	$6,000	–	**$6,000**
Travel	$5,683	$13,166	$56	$18,793	$111	**$18,904**
Major Equipment	$20,000	–	–	$20,000	–	**$20,000**
Minor Equipment & Supplies	$53,456	$2,736	–	$56,192	–	**$56,192**
Shipping	$5,000	–	–	$5,000	–	**$5,000**
Rent	$15,000	$14,303	–	$24,303	$5,000	**$29,303**
Construction	$106,684	$53,342	–	$160,026	–	**$160,026**
On-Campus Services	$13,276	$16,816	–	$13,276	$16,816	**$30,092**
Contracted Services	$19,050	–	–	$19,050	–	**$19,050**
Tuition	$3,000	$6,000	$3,000	$6,000	$6,000	**$12,000**
Direct Costs	$305,093	$202,358	$22,315	$415,800	$113,966	**$529,766**
Indirect Costs	$17,383	$28,799	$5,778	$26,148	$25,812	**$51,960**
Total	**$322,476**	**$231,156**	**$28,093**	**$441,948**	**$139,778**	**$581,726**

Salaries and Benefits

A breakdown of salaries, benefit rates and total cost per person is provided in Table 7. Percent time is calculated based on a 2,080 hour work-year for staff and 1,300 hour work-year for students. The $6,000 in subcontracts is to cover time for Barry Christopher.

Travel

Travel will cover trips to the test site in Lewistown, Montana, to monitor construction of the field test sections, observe the progression of damage during traffic loading and to collect data during testing. It is anticipated that 25 trips with varying numbers of staff per trip are necessary to accomplish the tasks associated with this research. Actual trips may vary depending on events during construction and monitoring of the field test sections. The anticipated cost of trips taken from Bozeman to Lewistown (TRANSCEND) and Helena are calculated based on the information contained in Table 8 and Table 9, respectively. Each anticipated trip is detailed in Table 10.

Table 7: Staff Salary and Benefit Information

Table 8: Anticipated Travel Costs to TRANSCENI

Category	Cost	Units
Rental Vehicle	$50	per day (SUV)
Trip Fuel	$125	per trip
Daily Fuel	$10	per day
Per Diem	$23	per person, per day
Motel	$60	per person, per night

Table 9: Anticipated Travel Costs to Helena

Category	Cost	Units
Rental Vehicle	$35	per day (car)
Fuel	$30	per trip
Per Diem	$23	per person, per day

Table 10: Itemization of Anticipated Trips to Helena and TRANSCEND

Trip No.	Task No.	No. of People	Days	Cost	Purpose	Attendees
1	0	2	1	$111	Kick-off meeting (Helena)	EC, SP
2	1	1	1	$208	Sample subgrade	MA
3	1	2	2	$457	Sample subgrade, base, ship to GA	EC, MA
4	2	3	4	$1,181	Install rut device	EC, JH, KF
5	2	3	4	$1,181	Install strain gages	EC, MA, GS
6	3	1	1	$208	Subgrade delivery	KF
7	3	3	1	$254	Pre-bid meeting with contractors	EC, SP, GS
8	3	1	2	$351	Monitor excavation	MA
9	3	2	4	$909	Monitor subgrade installation	EC, GS
10	3	2	4	$909	Monitor subgrade installation	EC, GS
11	3	2	4	$909	Monitor subgrade installation	EC, GS
12	3	5	2	$775	Install geosynthetics, base const.	EC, SP, BC, JH, MA
13	3	5	2	$775	Install geosynthetics, base const.	GS, US, US, KF, SS
14	3	2	2	$457	Monitor placement of base course	EC, SS
15	4	5	5	$2,200	Install wiring, conduit, DAQ	EC, JH, MA, GS, US
16	5	2	1	$231	Pick up rental test vehicle	GS, CD
17	5	2	1	$231	Paint lines, load and weigh truck	EC, GS
18	5	2	5	$1,135	Traffic/monitor test sections	EC, GS
19	5	2	5	$1,135	Traffic/monitor test sections	MA, GS
20	5	2	5	$1,135	Traffic/monitor test sections	MA, GS
21	5	2	5	$1,135	Traffic/monitor test sections	MA, GS
22	5	2	5	$1,135	Traffic/monitor test sections	EC, GS
23	5	2	1	$231	Return rental test vehicle	GS, CD
24	6	6	4	$1,997	Forensic excavations	EC, SP, KF, GS, US, US
25	8	2	1	$111	Final presentation (Helena)	EC, SP

EC = Eli Cuelho, SP = Steve Perkins, BC = Barry Christopher, MA = Michelle Akin, JH = Jason Harwood, KF = Keith Fortune, CD = Commercial Driver, GS = Graduate student, US = Undergrad student, SS = support staff

Major Equipment

Major equipment includes the light-weight deflectometer (LWD; $15,000) and equipment associated with the rut measuring device ($5,000). The LWD will allow researchers to quickly and more thoroughly assess and monitor the in-place properties of the subgrade and base course during construction, trafficking and the forensic investigations. The budget for the rut measuring device is $14,250, which is split between major equipment ($5,000), minor equipment and supplies ($5,000) and contracted services ($4,250). Details of its construction and anticipated use can be found in the Rut section on page 8 of this proposal.

Minor Equipment and Supplies

The budget for minor equipment and supplies is $56,192, which includes $51,192 for the nonexpendable and expendable equipment and supplies listed in Table 11, and $5,000 for the rut device. Nonexpendable minor equipment includes the vane shear device, the dynamic cone penetrometer (DCP) and a digital level with accessories. The remaining items in Table 11 are considered expendable.

Table 11: Itemized List of Anticipated Minor Equipment and Supplies

Item	Qty.	Cost	Purpose/Notes
Vane shear device	1	$2,000	subgrade characterization
DCP	1	$2,500	materials characterization
Digital level	1	$2,500	level, staff, tripod, batteries, accessories
Replacement vane	1	$200	replace vane on existing device
DCP tips	640	$1,376	40 per test section
LVDTs	45	$9,000	displacement measurements
Signal conditioners	45	$9,000	instrumentation
PWP sensors	35	$7,870	pore-water pressure measurements
Strain gages	26	$260	strain measurements
Buckets	30	$195	to transport materials
Plastic baggies	800	$200	to store materials
Super sacks	21	$105	to ship materials to GA
Enclosures	16	$2,400	houses sensors at each test section
Wire	1600	$2,000	data transfer
Fuel – test vehicle	1206	$1,206	$4/gallon, 4 mpg + 100 gal. for idling
Fuel – gen., equip.	320	$1,280	$4/gallon
Precision resistors	104	$1,248	instrumentation
Voltage regulators	32	$256	instrumentation
Circuit boards	20	$500	instrumentation
Screw terminals	64	$326	instrumentation
Charge controller	4	$240	power regulation
Soldering material	1	$30	instrumentation
Materials	5	$3,500	geosynthetics
Spray paint	6	$23	marking test sections
Batteries	8	$6	power supply
Threaded rod	36	$333	for LVDTs
Washers	128	$6	for LVDTs
Nuts	45	$7	for LVDTs
Fasteners	1	$15	screws
Clamps	45	$34	for LVDTs
Drill bits (pkg.)	1	$18	drilling
Tape	8	$60	for strain gages
Stakes	16	$16	delineation
Flagging (rolls)	2	$6	delineation
Epoxy	2	$8	adhesive
Environ. protection	26	$780	for strain gages
Pallets	20	$80	shipping
Microwave	1	$100	in-field moisture content
Dishes	4	$32	for drying soil
Water (gallons)	20	$25	sensor installation
Lab books	2	$8	documentation
Lumber (2x's)	8	$24	framing material
Lumber (plywood)	4	$80	hardware mounting
Plastic, 6 mil	8	$760	to cover test sections
Memory cards	4	$80	data storage
Plumbing – pipe	55	$221	wire conduit
Plumbing – fittings	128	$279	wire conduit

Shipping

WTI estimated that transporting several tons of subgrade, base course and geosynthetics to the laboratory in Atlanta for the large-scale box test would cost approximately $4500. The remaining $500 is needed to cover the cost of transporting geosynthetics from Bozeman to Lewistown and for transporting forensically extracted samples to a qualified testing lab.

Rent

Rental costs for this project include the use of the TRANSCEND test facility in Lewistown; renting associated tools, equipment and data acquisition hardware from TRANSCEND; a large vacuum truck to extract the base course during the forensic investigations; an excavator, mini-excavator and skid-steer tractor to move large piles of materials and perform clean-up of the test area; a trailer to haul materials and equipment; a water trailer to maintain proper moisture content during testing, and the test vehicle. Table 12 summarizes these costs.

Table 12: Itemized List of Anticipated Rental Costs

Rental Item	Cost	Unit	Qty	Total
TRANSCEND–monthly rate	$2,500	per month	5	$12,500
TRANSCEND –data trailers	$500	per month	5	$2,500
TRANSCEND –land alteration fee	$5,000	per project	1	$5,000
Vacuum truck	$900	per day	3	$2,700
Excavator	$500	per day	1	$500
Mini-excavator	$100	per day	5	$500
Skid-steer	$100	per day	5	$500
Trailer	$25	per day	12	$300
Water trailer	$70	per day	4	$280
Portable toilet	$110	per month	2	$220
Test vehicle	$3,000	per month	1	$3,000
Test vehicle	$250	per day	2	$500
Test vehicle	$0.50	per mile	1106	$553

Construction

The cost of construction was based on an estimate provided by a Lewistown-based contractor. The estimated total cost of $160,026 does not include any contingencies. Estimates for this work were based on the following items: cleaning, enlarging and lining the trench = $23,352; providing and constructing the subgrade = $77,333; constructing the base course = $59,341.

On-Campus Services

On-campus services include geosynthetic material testing to determine interaction and constitutive material properties. These services will be provided by qualified laboratory technicians at Montana State University. The number of tests assumes that 12 geosynthetics are evaluated as part of this project.

Table 13: Itemized List of Anticipated Material Tests Conducted Using On-Campus Services

Test	No. of Replicates	Material Directions	No. of Tests	Cost per Test	Total Cost
Resilient Interface Shear	1	1	12	$1,250	$15,000
Cyclic In-Air Tension	5	2	120	$75	$9,000
Monotonic In-Air Tension[a]	5	2	120	$17	$2,040
Aperture Stability Modulus	3	1	36	$20	$720
Junction Stiffness	6	2	144	$17	$2,448
Monotonic In-Air Tension[b]	2	2	52	$17	$884

[a] tests conducted on virgin geosynthetics
[b] tests conducted on materials extracted during forensic investigations (13 geosynthetics)

Contracted Services

Contracted services totals $19,050 and includes two main items, materials testing ($14,800) and machining for the rut measurement device ($4,250). Table 14 summarizes the laboratory testing to be completed by contracted services.

Table 14: Anticipated Lab Tests Conducted by Contracted Services

Test	No. of Tests	Cost per Test	Total
Box tests	1	$7,000	$7,000
Resilient modulus – subgrade	3	$550	$1,650
Resilient modulus – base	3	$550	$1,650
Repeated load triaxial – subgrade	3	$750	$2,250
Repeated load triaxial – base	3	$750	$2,250

Tuition

Tuition is needed to support one graduate student throughout the duration of the project. Tuition costs are $3000 per semester, and the graduate student will work on this project for a two-year period (four semesters), which brings the total cost of tuition to $12,000.

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FHWA (1995). Geosynthetic Design and Construction Guidelines, Federal Highway Administration, Report No. FHWA-HI-95-038, 417 p.

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Appendix A: Two-Page Résumés

ELI V. CUELHO, P.E.

Research Engineer
Western Transportation Institute
Montana State University–Bozeman
Bozeman, MT 59717
(406) 994-7886
elic@coe.montana.edu

EDUCATION

1998, Master's of Science in Civil Engineering, Montana State University – Bozeman
1995, Bachelor's of Science in Civil Engineering, Montana State University – Bozeman

PROFESSIONAL REGISTRATION

2002, Professional Engineering License, State of Montana

PROFESSIONAL AFFLIATIONS

2000–present	International Geosynthetics Society (IGS)
2001–present	American Society of Civil Engineers (ASCE)
2004–present	Transportation Research Board Committee Member – Dynamics and Field Testing of Bridges (AFF40)
2005–present	American Society for Testing and Materials (ASTM)
2006–present	Transportation Research Board Committee Member – Committee on Geosynthetics (AFS70)

RELEVANT PROFESSIONAL EXPERIENCE

1998–present	Research Engineer, Western Transportation Institute, Montana State University – Bozeman
2006–2007	Adjunct Instructor, Civil Engineering Department, Montana State University – Bozeman
1995–1998	Research Assistant, Civil Engineering Department, Montana State University – Bozeman
Summer 1995	Research Aide, Western Transportation Institute, Montana State University – Bozeman
Summer 1994	Geotechnical Assistant – Intern, Fisher Sand & Gravel, Dickinson, ND

RELEVANT PROJECT EXPERIENCE

"Validation of Rehabilitation Strategies to Extend the Service Life of Concrete Bridge Decks," Eli Cuelho – PI with Jerry Stephens, Caltrans and the Western Transportation Institute, $619,339, July 2008 to June 2012.

"Field Investigation of Geosynthetics Used for Subgrade Stabilization," Eli Cuelho – PI with Steve Perkins, NAUE Gmbh & Co. KG, Montana Department of Transportation and the Western Transportation Institute, $247,816, March 2008 to June 2009.

"Development of a Cold Region, Rural Transportation Research Test Bed in Lewistown, Montana," Eli Cuelho – PI, US Department of Transportation, $3,800,000, October 2006 to September 2010.

"Feasibility of Using a Gyratory Compactor to Determine Compaction Characteristics of Base Course Aggregates," Eli Cuelho – co-PI with Bob Mokwa, Western Transportation Institute, $45,000, January 2005 – December 2006.

"Comparative Analysis of Coarse Surfacing Aggregates Using the Micro-Deval, L.A. Abrasion and Sulfate Soundness Tests," Eli Cuelho – co-PI with Bob Mokwa, Montana Department of Transportation, $23,323, September 2005 – December 2006.

"Preventive Maintenance Treatments: A Synthesis of Highway Practice," Eli Cuelho – co-PI with Bob Mokwa, Montana Department of Transportation, $25,000, May 2005 – June 2006.

"Cost Effectiveness of Crack Sealing Materials and Techniques for Asphalt Pavements," Eli Cuelho – PI (as of June 2001), Western Transportation Institute, Montana State University – Bozeman University Transportation Center; $122,560; October 1995 – March 2004.

RELEVANT PUBLICATIONS

Cuelho, Eli and Perkins, Steve. "Field Investigation of Geosynthetics Used for Subgrade Stabilization," Final report to the Montana Department of Transportation, FHWA/MT-09-003/8193, July 2009.

Cuelho, Eli; Mokwa, Robert and Obert, Keely. "Comparative Analysis of Coarse Surfacing Aggregate Using Micro-Deval, L.A. Abrasion and Sodium Sulfate Soundness Tests," Final report to the Montana Department of Transportation, FHWA/MT-06-016/8117-27, January 2007.

Cuelho, Eli; Mokwa, Robert and Akin, Michelle. "Preventive Maintenance Treatments of Flexible Pavements: A Synthesis of Highway Practice," Final report to the Montana Department of Transportation, FHWA/MT-06-009/8117-26, October 2006.

Cuelho, Eli; Smolenski, Peter; Stephens, Jerry and Johnson, Jeff. "Evaluating Concrete Bridge Deck Performance – Final Project Report," Final report to the Montana Department of Transportation, FHWA/MT-06-006/8156-002, June 2006.

Perkins, S. W., Christopher, B. R., Cuelho, E. L., Eiksund, G. R., Schwartz, C. S. and Svanø, G. (2009) "A mechanistic-empirical model for base-reinforced flexible pavements," International Journal of Pavement Engineering,10:2,101-114.

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Mokwa, B.; E. Cuelho and M. Browne (2008) "Laboratory Testing of Soil Using the Superpave Gyratory Compactor," Proceedings of the Transportation Research Board 2008 Annual Conference, Washington, D.C.

Perkins, S. W. and E. V. Cuelho, (2005) "Comparison of a Mechanistic-Empirical Design Model to Measured Performance for Base-Reinforced Pavements," Proceedings, NAGS 2005/ GRI 19 Conference, Las Vegas, NV.

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Cuelho, Eli (1998), "Determination of Geosynthetic Constitutive Parameters and Soil/Geosynthetic Interaction by In-Air and In-Soil Experiments," M.S. Thesis, Montana State University – Bozeman.

STEVEN W. PERKINS, PHD, P.E.

Professor
Civil Engineering Department
Montana State University–Bozeman
Bozeman, MT 59717
(406) 994-6119
stevep@ce.montana.edu

EDUCATION

Ph.D., Civil Engineering, University of Colorado, Boulder, 1991

M.S., Civil Engineering, University of Colorado, Boulder, 1985

B.S., Civil Engineering, Virginia Polytechnic Institute and State Univ., Blacksburg, Cum Laude

PROFESSIONAL REGISTRATION

1993, Licensed Professional Engineer, State of Montana

RELEVANT PROFESSIONAL EXPERIENCE

1991–Present	Professor, Montana State University, Department of Civil Engineering, Bozeman, Montana
2007–2011	Co-Instructor, National Highway Institute, Short Courses on Geosynthetics Engineering Workshop and Geotechnical Aspects of Pavements
2006–2007	Visiting Research Engineer; Norwegian Geotechnical Institute (NGI), Oslo, Norway
1986–1988	Engineer; Kleinfelder and Associates, Geotechnical Engineers, Fairfield, California

RELEVANT WORKSHOPS, SHORT COURSES, AND TRAINING PRESENTATIONS

"Geosynthetics in Transportation Infrastructure Applications," A Half-Day Training Course for the Montana Department of Transportation, Bozeman, Montana, January 7–8, 2003.

"Design of Geosynthetic Reinforced Flexible Pavements Using the MSU-GRFP Design Model," Montana Department of Transportation, Helena, Montana, November 2002.

"Geosynthetics in Pavement Systems," Invited presentation at the Idaho Asphalt Conference, Moscow, Idaho, October 22, 2009.

Geosynthetics in Roadway Systems, Perkins, S.W., A Half-Day Workshop, Geosynthetics Conference 2009, Salt Lake City, Utah, February 27, 2009.

Geotechnical Aspects of Pavements, Berg, R.R., Perkins, S.W. and Schwartz, C.S., NHI short course, Columbus, OH, September 18-20, 2007.

Geosynthetics in Roadway Systems, Schwartz, C.S. and Perkins, S.W., Full-Day Workshop, Geosynthetics Conference 2007, Washington, DC, USA, January 18, 2007.

Pavement Design with Geosynthetics, Christopher, B.R., Berg, R.R. and Perkins, S.W., Full-Day Workshop, Geosynthetics Conference 2001, Portland, OR, USA, February 11, 2001.

Workshop on Flexible Pavement Design, Invited Feature Speaker, Lund Institute of Technology, Lund Sweden, March 2004.

New Trends in Pavement Structures, Invited Participant, Fourth International Conference and Exhibition on Road and Airfield Pavement Technology, Kunming China, April 2002.

RELEVANT TEACHING EXPERIENCE

CET 302	Soils and Foundations	Fall 2007, 2008; Spring 2009
CE 320	Geotechnical Engineering	Fall 1992-1995; Spring 2004, 2005, 2006, 2008, 2009
CE451	Highway Pavements	Fall 2002, 2004; Spring 2006, 2008

RELEVANT PUBLICATIONS

Synthesis of Warm Mix Asphalt Paving Strategies for Use in Montana Highway Construction, Perkins, S.W., Montana Department of Transportation, U.S. Department of Transportation, Federal Highway Administration, Washington, DC, Report No. FHWA/MT-09-009/8117-38, 209 p., November, 2009

Geosynthetic Reinforcement of the Aggregate Base/Subbase Courses of Flexible Pavement Structures – GMA White Paper II, Berg, R.R., Christopher, B.R. and Perkins, S.W., Geosynthetic Materials Association, Roseville, MN, USA, 176 p., 2000.

"A Mechanistic-Empirical Model for Base-Reinforced Flexible Pavements," Perkins, S.W., Christopher, B.R., Cuelho, E.V., Eiksund, G.R., Schwartz, C.S. and Svanø, G., International Journal of Pavement Engineering, Vol. 10, No. 2, pp. 101-114, 2009.

"Mechanistic-Empirical Design Model Predictions for Base-Reinforced Pavements," Perkins, S.W. and Cuelho, E.V., Transportation Research Record 1989, Transportation Research Board, National Research Council, Low-Volume Roads, Vol. 2, pp. 121-128, 2007.

"Evaluation of Base-Reinforced Pavements Using a Heavy Vehicle Simulator," Perkins, S.W. and Cortez, E.R., Geosynthetics International, Vol. 12, No. 2, pp. 86-98, 2005.

"Pore Water Pressure Influence on Geosynthetic Stabilized Subgrade Performance," Christopher, B.R., Perkins, S.W., Lacina, B.A. and Marr, W.A., Proceedings of the Conference Geosynthetics 2009, Salt Lake City, Utah, USA, 2009.

"Field Construction and Trafficking of an Unsurfaced Geosynthetic-Stabilized Road," Cuelho, E.V., Perkins, S.W., Hauck, J., Akin, M.R. and von Maubeuge, K., Proceedings of the Conference Geosynthetics 2009, Salt Lake City, Utah, USA, 2009.

BARRY R. CHRISTOPHER, PHD, P.E.

Geotechnical Engineering Consultant
Christopher Consultants
210 Boxelder Lane
Roswell, GA 30076
(770) 641-8696
barryc325@aol.com

EDUCATION

Ph.D. (Civil Engineering) – Purdue University, 1993
M.S. (Civil Engineering) – Northwestern University, 1979
B.S. (Civil Engineering) – University of North Carolina at Charlotte, 1975

PROFESSIONAL REGISTRATION

Professional Engineer: Illinois, Maryland, Michigan, South Carolina, Georgia and Virginia.

PROFESSIONAL SOCIETIES AND AFFILIATIONS

American Society of Civil Engineers and GeoInstitute, Member
American Society for Testing and Materials, Fellow (past chair) of Committee D35
North American and Int'l Geosynthetic Societies (past president US chapter and Council Member)
International Society for Soil Mechanics and Foundation Engineers
National Society of Professional Engineers, Member
Transportation Research Board, Member

PROFESSIONAL EXPERIENCE

1994-Present Geotechnical Engineering Consultant - Independent geotechnical engineer with containment system design, geosynthetics application and design; geotechnical and geosynthetics laboratory testing; insitu measurements; and field instrumentation. Co-principal in development of course curriculum, co-author of referenced design manuals, and instructor for five FHWA/NHI courses, as well as manager/alternate instructor on two courses. Co-principal of SHRP R02 initiative on "Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform." Geotechnical staff consultant for GeoComp/GeoTesting Express, Haley and Aldrich, JMT, Kleifielder, MacTec, and Shannon and Wilson.

1989–1994 Vice President Technical Services - Polyfelt Americas. Responsible for applications engineering, Research and Development, and product quality assurance for worldwide manufacturer of geotextiles. Consulted with users, owners and agencies on geosynthetic design for roadways, waste containment and earth structures applications.

1978–1989 Principal Engineer (last position held) - STS Consultants, Ltd. Responsible for design and technical review of geotechnical projects as well as direction and technical evaluation for all STS geotechnical and materials laboratories. Specialty consulting for projects involving earth retention system design, reinforced soil design, geosynthetic evaluation, geo-environmental containment systems, pavement system evaluation, in-situ instrumentation and geophysical evaluation. Consultant and principal engineer on over a hundred commercial and transportation projects involving various aspects of roadway design and construction including planning and directing subsurface exploration programs, subgrade support design, and flexible and/or rigid pavement design. Projects included: new and reconstructed/rehabilitated roadways, runways, storage yards, warehouses, and parking facilities.

REPRESENTATIVE PUBLICATIONS RELATED TO PAVED AND UNPAVED ROADWAYS

Christopher, B.R. and Holtz, R.D. "Geotextile Engineering Manual," U.S. Department of Transportation, Federal Highway Administration, Washington DC, Report No. FHWA-TS-86/203, March 1985, 1044 p.

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Christopher, B.R., Schwartz, C., and Boudreau, R., Geotechnical Aspects of Pavements, U.S. Department of Transportation, Federal Highway Administration, Washington DC, FHWA-NHI-05-037, 2006.

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Perkins, S.W., Christopher, B.R. and Lacina, B., "Mechanistic-Empirical Design Method for Unpaved Roads Using Geosynthetics," Proceedings of the Fourth European Geosynthetics Conference, Edinburgh, United Kingdom, International Geosynthetics Society, 2008.

MICHELLE R. AKIN, P.E.

Research Engineer
Western Transportation Institute
Montana State University–Bozeman
Bozeman, MT 59717
(406) 994-6356
michelle.akin@coe.montana.edu

EDUCATION

2006, M.S., Civil Engineering, Montana State University, Bozeman
2004, B.S., Environmental Resources Engineering, Humboldt State Univ., Arcata, Magna Cum Laude

PROFESSIONAL REGISTRATION

Professional Engineer, State of Montana, License #20178, 2011

PROFESSIONAL AFFLIATIONS

2007–present	Transportation Research Board (TRB) "Friend" of Committees: Low-Volume Roads, Winter Maintenance, and Engineering Behavior of Unsaturated Soils
2002–2006	Society of Women Engineers (SWE)

RELEVENT PROFESSIONAL EXPERIENCE

2011–present	Research Engineer, Western Transportation Institute, Montana State University – Bozeman
2006–2011	Research Associate, Western Transportation Institute, Montana State University – Bozeman
2004–2006	Graduate Teacher Assistant, Civil Engineering Department, Montana State University – Bozeman
Summer 2005	Graduate Assistant, Western Transportation Institute, Montana State University – Bozeman
Summer 2003	Undergraduate Research Student, Western Transportation Institute, Montana State University – Bozeman

RELEVENT PROJECT EXPERIENCE

"Development of a Cold Region Rural Transportation Research Test Bed in Lewistown, Montana," Eli Cuelho – PI, USDOT Office of Innovation, Research and Education, $3,530,112, September 2006 – September 2010.

"Investigating Innovative Research Opportunities Related to Highway Infrastructure Design and Maintenance," Eli Cuelho – PI, Western Transportation Institute, $142,495, January 2004 – September 2006.

"Measurement and Evaluation of Subgrade Soil Parameters, Phase I: Synthesis of Literature," Robert Mokwa – PI, Montana Department of Transportation, $39,528, December 2008 – August 2009.

"Field Investigation of Geosynthetics Used for Subgrade Stabilization," Eli Cuelho – PI, Steven Perkins – co-PI, NAUE GmbH & Co. KG, Montana Department of Transportation, Western Transportation Institute, $247,816, March 2008 – February 2009.

"Preventive Maintenance Treatments: A Synthesis of Highway Practice," Eli Cuelho – co-PI with Bob Mokwa, Montana Department of Transportation, $25,000, May 2005 – June 2006.

"ACRP Synthesis 11-03/Topic S10-03: Airport Pavement Deicing Products: Use and Corrosion Damage," Xianming Shi – PI, Airport Cooperative Research Program, $25,000, November 2007 – April 2008.

RELEVENT PUBLICATIONS

Cuelho, Eli; Mokwa, Robert and Akin, Michelle. "Preventive Maintenance Treatments of Flexible Pavements: A Synthesis of Highway Practice," Final Report to the Montana Department of Transportation, October 2006.

Western Transportation Institute; "Basic Information on Typical Sensors Used to Monitor Bridges," Prepared for the Transportation Research Board 86th Annual Meeting, Workshop #107: Making Sense of Sensors Used to Monitor Bridges, January 21, 2007.

Cuelho, E.V., Perkins, S.W., Hauck, J., Akin, M.R., von Maubeuge, K. "Field Construction and Trafficking of an Unsurfaced Geosynthetic-Stabilized Road," Proceedings: Geosynthetics 2009, Salt Lake City, Utah, February 25-27, 2009.

Mokwa, Robert and Akin, Michelle. "Measurement and Evaluation of Subgrade Soil Parameters: Phase I—Synthesis of Literature," Final Report to the Montana Department of Transportation, September 2009.

Akin, Michelle and Xianming Shi. "Development of Standardized Test Procedures for Evaluating Deicing Chemicals," Draft Report to the Clear Roads Pooled Fund, October 2009.

Shi, X., Akin, M., Pan, T., Fay, L., Liu, Y., Yang, X. "Deicer Impacts on Pavement Materials: Introduction and Recent Developments," The Open Civil Engineering Journal, 2009, vol 3, pp.16-27.

HONORS AND OTHER ACTIVITIES

Mary and Robert Sanks Graduate Fellowship recipient, 2005–2006

Mary and Robert Sanks Graduate Fellowship, Presidential Graduate Scholarship, and John H and Rosalie L Morrison Scholarship recipient, 2004–2005

Outstanding Environmental Resources Engineering Graduate, Humboldt State University, 2004

Judged Outstanding in Interdisciplinary Contest in Modeling, sponsored by Consortium for

Mathematics and its Applications (COMAP), publication followed, 2003

Member of Humboldt State University's water treatment competition team, 2003

Vice President of Planning for College Success, HSU student chapter of National Society of Collegiate Scholars, 2002–2004

Freshman Chemistry Achievement Award, bestowed Handbook of Chemistry and Physics from CRC Press, 1999

JASON HARWOOD, P.E.

Research Associate
Western Transportation Institute
Montana State University–Bozeman
Bozeman, MT 59717
406-994-7176
jason.harwood@coe.montana.edu

EDUCATION

Master of Science, Mechanical Engineering
Montana State University, Bozeman, May 2007
Thesis: *Efficient Finite Element Modeling Across Optical Length Scales*

Bachelor of Science, Mechanical Engineering
University of Idaho, Moscow, May 2005

PROFESSIONAL AFFLIATIONS

Tau Beta Pi Engineering Honor Society

KEY QUALIFICATIONS

Jason Harwood is a Research Associate at WTI with a Master's degree in Mechanical Engineering from Montana State University. Over the past three years, he has helped design, construct, and use the snowmaking system at TRANSCEND, a cold region research facility in Lewistown, Montana. He is also working to develop an Accelerated Pavement Tester for a pavement rehabilitation projects. Additionally, Jason assists with many other research activities including geosynthetic testing, concrete testing, data acquisition system setup, field testing at TRANSCEND, and laboratory equipment design.

EMPLOYMENT HISTORY

Research Associate, Western Transportation Institute, Montana State University, Bozeman, Montana, June 2007–current

Graduate Research Assistant, Mechanical Engineering Department, Montana State University, Bozeman, Montana, August 2005–May 2007

Wilderness Crew Staff, Washington Family Ranch, Young Life, Antelope, Oregon, Summers 2005 & 2006

Engineering Assistant, Nelson Irrigation, Walla Walla, Washington, Summer 2004

Product Design Assistant, Martin Archery, Walla Walla, Washington, Summer 2003

PROJECT EXPERIENCE—CURRENT

Establishing Best Practices – Snow/Ice Removal in California

Develop guidelines for optimal snow and ice removal operations designed specifically for California highway environments.

Development of a Cold Region Rural Transportation Research Test Bed in Lewistown, Montana

To improve transportation maintenance, operations and safety with cold-regions research through the collaboration of academia, industry and government.

Validation of Rehab Strategies to Extend the Service Life of Concrete Bridge Decks

The objective of this research is to investigate the long-term effectiveness of Caltrans' preservation and rehabilitation strategies for concrete bridge decks. Caltrans currently employs high molecular weight methacrylate (HMWM)-based crack sealing and polyester overlay. This research will also explore the value of Portland cement concrete (PCC) and asphalt concrete (AC) overlays on bridge decks, and identify the appropriate treatment time and frequency for these strategies.

PROJECT EXPERIENCE—PAST

Designing and Manufacturing a Removable Seed and Sediment Trap for the Undercarriage of Vehicles

The purpose of this project is to design and manufacture a removable seed and sediment trap for the undercarriage of a vehicle, allowing for minimal seed damage when seeds are removed for inspection.

Field Investigation of Geosynthetics Used for Subgrade Stabilization

This project aims to construct test sections in the field to investigate the relative benefit of various geosynthetics available on the market to an unpaved road.

HONORS AND AWARDS

University Honors Certificate, University of Idaho

Member of 2002-2003 University of Idaho Clean Snowmobile Challenge team

Student tutor for Academic Assistance Program, University of Idaho

KEITH A. FORTUNE

Project Assistant
Western Transportation Institute
Montana State University–Bozeman
Bozeman, MT 59717
406-994-7715
keith.fortune@coe.montana.edu

EDUCATION

B.S., Land Rehabilitation, Minor in Soils, Montana State University, 2004
A.A.S., Environmental Technology, Colorado Mountain College, 1997

EMPLOYMENT HISTORY

2009–present: *Project Assistant, Western Transportation Institute, Bozeman, MT*

General duties include: Provide support and management to transportation research projects associated with the Winter Maintenance and Effects Program, the Corrosion and Sustainable Infrastructure Laboratory, and the Infrastructure Maintenance and Materials Program. Specific responsibilities include laboratory testing, large scale field experimentation, sampling and design management, and graduate and undergraduate training and supervision.

2006–2009: *Small Business Owner, At Your Service Handyman, LLC, Bozeman, MT*

General duties included managing clients and client relations, project management, and financial and business administration. Specific responsibilities included miscellaneous home repair, residential remodels, commercial property maintenance, landscaping, and overall business management.

2003–2007: *Environmental Scientist, Resource Technologies Inc., Bozeman, MT*

General duties included conducting groundwater and soil remedial investigations and processes and producing and implementing Phase I and Phase II Environmental Site Assessments. Specific responsibilities included environmental sampling of groundwater, wastewater, and soils, conducting remedial investigations and processes of sites contaminated with petroleum hydrocarbons including project management, excavation oversight, sampling, data analysis, and reporting as well as operation and maintenance of soil vapor extraction and free-product recovery systems. Duties also included land reclamation, specifically soil stabilization treatability studies, contractor oversight on large-scale soil remediation project, waste characterization data analysis, and summarization. Also performed Phase I and Phase II Environmental Site Assessments for commercial and residential real estate transactions including historical and environmental records research, site investigations, work plan composition, sampling outline, reclamation procedures, data analysis, and reporting.

2002–2003: *Soil Research Assistant, Montana State University, Bozeman, MT*

General duties included processing and analyzing soils for inorganic carbon using light reflectance with an Analytical Spectral Device. Specific responsibilities included preparation of soil samples and data collection using an Analytical Spectral Device.

2001–2002: *Project Manager, Natural Resource Management Inst., Leadville, CO*

General duties included supervision and management of federal reclamation projects in the Leadville area. Responsibilities included supervision of twelve field technicians, carried out a large scale water sampling project with NASA, organized and controlled bidding procedures to attain contractors and provided contractor oversight of several large scale EPA Superfund projects, and drafting and oversight of a large scale storm water management plan.

1997–2001: *Environmental Technician, Climax Molybdenum Co., Leadville, CO*

General duties included land rehabilitation, project management and engineering, storm water management, waste management, heavy equipment operations, and Colorado State and Federal environmental laws and regulations compliance. Specific responsibilities included soil fertilization, landscape design, hydro-seeding/mulching, hand seeding, and native vegetation planting, project bidding procedures, contractor oversight, and small project design. Also Asbestos identification and removal oversight, hazardous waste collection, packaging and shipping, and mine related hazardous spill response first responder.

PROJECT EXPERIENCE—CURRENT

Inhibitor Longevity and Deicer Performance: A Pooled Fund Study

Funded by the Pacific Northwest Snowfighters Association, the purpose of this project is to evaluate the performance and longevity of corrosion inhibitors in anti-icers and deicers, both in storage and road applications, and to develop a reliable method of quantifying inhibitor concentrations in anti-icers and deicers in storage and before and after roadway application.

TRANSCEND: Development of a Cold Region, Rural Transportation Research Test Bed

Located in Lewistown Montana, Transcend is a large scale research facility designed for research and testing on surface transportation issues. The facility incorporates over 200 acres of land and four miles of paved test track and is equipped with state-of-the-art snowmaking equipment. The facility is designed to suite multidisciplinary large scale experiments for the transportation industry.

Building Green: Development and Evaluation of an Environmentally Friendly Concrete

Funded by the National Science Foundation the objective of this project is to identify and characterize fly ashes from several power plants located throughout the country and use them to fully replace conventional Portland cement in concrete mixtures and utilize recycled pulverized glass as an aggregate. Resulting designs will be tested to determine their fundamental engineering properties and durability.

Establishing Best Practices of Removing Snow and Ice from California Roadways

Funded by the California Department of Transportation the objective of this project is to develop guidelines for optimal snow and ice removal from California roadways given various storm scenarios and chemical deicers. The project consists of both laboratory experimentation and full scale field experimentation using the snow making facility of TRANSCEND in Lewistown, Montana, to produce typical weather environments specific to California roadways.