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# Use of Geosynthetics on Paved and Unpaved Rural Roads

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## ABSTRACT

This paper is written with two basic objectives in mind. First, it is written to promote the use of geosynthetics on rural, low-volume roads where these materials seem under-utilized. Second, this paper will document the many useful, cost-effective, and often creative applications of geosynthetics used on low-volume roads. Geosynthetics have been used in a wide range of applications on rural and forest roads across America over the past 40 years. Some of the earliest uses involved reinforcement in simple walls, drainage/filtration in geocomposite underdrains, and subgrade stabilization on forest roads. These early efforts were typically “experimental”. Over time geosynthetic use became better defined by function, where use was specified for drainage, filtration, separation, or reinforcement. Road uses commonly involved separation of soft subgrade soils and aggregate, and as reinforcement in mechanically stabilized structures.

New combinations of materials have been developed, such as drainage geocomposites, multi-layer filters, lateral, in-plane drainage, geogrids with geotextiles, geofoam, geocells, and many applications in erosion control. Much more attention is given today to quality control and properties testing to better characterize the materials. Although use of geosynthetics has gained wide acceptance in many sectors of civil engineering and highway construction, their use is still limited on rural roads, both nationally and internationally. Because of the many useful aspects of geosynthetics in engineering design, their uses as part of “best engineering practices” are valuable to make roads last their design life, be cost- effective, and be more resilient in this time of climate change.

## RESUMEN

Este documento está escrito con dos objetivos. Primero, está escrito para promover el uso de geosintéticos en caminos rurales, donde estos materiales parecen subutilizados. Segundo, este documento documentará las muchas aplicaciones útiles, rentables y a menudo creativas de geosintéticos utilizados en caminos de bajo volumen. Los geosintéticos se han utilizado en una amplia gama de aplicaciones en caminos rurales y forestales en los Estados Unidos durante los últimos 40 años. Algunos de los primeros usos involucraron refuerzo en muros simples, drenaje / filtración en desagües geocompuestos y estabilización de subrasante en caminos forestales. Estos primeros esfuerzos fueron típicamente “experimentales”. Con el tiempo, el uso de geosintéticos se definió mejor por la función, donde se especificó el uso para drenaje, filtración, separación o refuerzo. Usos comúnes involucraron separación entre suelos blandos y agregados, y como refuerzo en estructuras mecánicamente estabilizadas.

Se han desarrollado nuevas combinaciones de materiales, como geocompuestos de drenaje, filtros multicapa, drenaje lateral en-plano, geomallas con geotextiles, geoespuma, geoceldas y muchas aplicaciones en el control de la erosión. Hoy se presenta mucha más atención al control de calidad y a las pruebas de propiedades para caracterizar mejor los materiales. Aunque el uso de geosintéticos ha ganado una gran aceptación en muchos sectores de la ingeniería civil y la construcción de carreteras, su uso aún es limitado en caminos rurales, tanto a nivel nacional como internacional. Debido a los muchos aspectos útiles de los geosintéticos en el diseño de ingeniería, sus usos como parte de las “mejores prácticas de ingeniería” son valiosos para hacer que las carreteras duren su vida útil de diseño, sean rentables, y sean más resistentes en esta época de cambio climático.

## 1. INTRODUCTION

The two basic objectives of this paper are 1) to promote the use of geosynthetics on rural, low-volume roads where the materials seem under-utilized, and 2) to document the many useful, cost-effective, and often creative applications of geosynthetics that have been used on low-volume roads. Geosynthetics have been used in a wide range of applications on rural and forest roads across America over the past 40 years. Some of the earliest uses involved reinforcement in simple walls, drainage/filtration in geocomposite underdrains, and subgrade stabilization on forest roads. These early efforts were typically “experimental”. Over time geosynthetic use became better defined by function, where use was specified for drainage, filtration, separation, or reinforcement. Road uses were typically in underdrains to keep a granular filter material clean, for separation of aggregate over soft subgrade soils to keep the aggregate from becoming contaminated, as reinforcement layers within a mechanically stabilized earth retaining wall or reinforced fill, and as interlayers within a pavement.

Today geosynthetic use is more sophisticated and better defined, where materials for each function have specific strength and durability properties appropriate for their use, as outlined in *Geosynthetic Design and Construction Guidelines: Reference Manual* (Holtz et al. 2008). This manual provides design criteria for use of geosynthetics in drainage, filtration, separation, and reinforcement applications. Also, new combinations of materials have been developed, such as drainage geocomposites, multi-layer filters, lateral, in-plane drainage, geogrids with geotextiles, geofoam, geocells, and many applications in erosion control, as well as other creative uses. In-plane drainage offers a valuable method for drainage of paved structural sections. Geocells are being used in a variety of ways for slope protection, in walls, to reinforce subgrades, and for low-water crossings. A wide variety of geosynthetic materials are being used in erosion control for mats, nettings, drainage structures, and with bioengineering methods. Much more attention is given today to quality control and properties testing to better characterize the geosynthetic materials.

Although use of geosynthetics has gained wide acceptance in many sectors of civil engineering and highway construction, their use is still limited on rural and low-volume roads, both nationally and internationally. Because of the many useful aspects of geosynthetics in engineering design, their uses as part of “engineering best practices” are valuable to make roads last their design life, be cost-effective, and help develop more resilient designs that are less vulnerable to storms in this time of climate change. Thus, an objective of this paper is to promote the use of geosynthetic materials in low-volume road design and construction.

## 2. HISTORIC USES

Early uses of geosynthetic materials on forest roads began in the 1970’s. Uses generally included drainage measures such as filter cloth in underdrains and in geocomposite drains, subgrade separation to build roads over soft soil deposits, and in a wide variety of mechanically stabilized earth (MSE) retaining walls, including geotextile wrapped-face walls, lightweight sawdust walls, and other types of MSE walls using geosynthetic reinforcement (Steward et al. 1977).

### 2.1 Geocomposite Drains

The concept of geosynthetic use in underdrains was first introduced in an ASCE Irrigation and Drainage Division journal article (Healy and Long 1972). Their prefabricated “filter-fin” subsurface drain, purposes as an alternative to a conventional gravel vertical trench drains, involved use of a polyester butterfly cloth or nylon chiffon material enveloped around a round, vinyl plastic reed curtain core material. This design led to the modern-day geocomposite drain using a woven or nonwoven geotextile wrapped around an impermeable waffle-like or plastic mesh core material. Today, this type of drain has commonly replaced the traditional gravel underdrain because of ease of installation and cost savings. The geocomposite drain is then placed around or inside a longitudinally sliced plastic pipe to drain off the water. On rural highways, short geocomposite drains are commonly used as “edge drains” to remove water from the structural section. Figure 1 shows the installation of a geocomposite underdrain along a national forest highway in California in 1976.

Figure 1. Installation of a geocomposite drain along a forest road in California, 1976.

## 2.2 Geotextile Reinforced Retaining Walls

Following the successful construction and performance of very early geosynthetic reinforced retaining walls in the Pacific Northwest in 1974, a large number of other geosynthetic-reinforced walls were constructed. The Forest Service published the *Retaining Wall Design Guide* (Driscoll 1979) documenting the theory and design methodology behind a variety of retaining structures, including gravity structures and mechanically stabilized earth (MSE) structures. This publication was updated by Mohney (editor) in 1994, primarily to emphasize MSE methodologies, reinforced soil-type wall systems, the use of reinforced fills, and general advances with geosynthetic materials. Much of this information is still in use today. Figure 2 shows an early geotextile wall constructed on a storm damage site on a national forest road.

Figure 2. A geotextile wall constructed on a forest road in California in 1983.

A variety of MSE walls using either geotextiles or geogrids for soil reinforcement were built. Geosynthetic-reinforced soil structures included geotextile-reinforced walls, modular-block walls, tire-faced walls, timber and straw-bale-faced walls, and lightweight wood chip walls. Geotextile face-wrapped walls, sometimes known as “burrito walls,” have been the least expensive MSE wall built to date. Figure 3 shows both a timber-faced, geogrid reinforced wall and a tire-faced wall with geotextile reinforcement under construction.

Lightweight sawdust or wood chip walls were used when it was important to reduce the weight and driving forces on an unstable slope. Lightweight materials are particularly useful on large slides or unstable mountainous terrain where it may be difficult to exactly define the limits of the slide, where alternative routes are impractical, or where the depth to suitable foundation material for a conventional structure is great. With a density of about 336 kg/cu meter, the wall weight is reduced by about 70%. Long-term monitoring has shown little to no degradation of the wood fiber in the 20-year-old fills and walls where air and water could not get to the wood. A variety of lightweight materials have ultimately been used in walls, including wood fiber, shredded tires, and geofoam.

a) Timber-faced Wall

b) Tire-faced Wall

Figure 3. Construction of a timber-faced wall and a tire-faced wall, both with geosynthetic reinforcement.

## 2.3 Reinforcement over Soft Soils

Early use of geotextiles was made by timber purchasers in the Pacific Northwest on low-volume forest roads by placing a layer of geosynthetic material (for separation and support) on a lightly cleared path on weak native soil, and then placing aggregate or granular fill material on the roadway. Test sections were constructed where design theories could be checked, costs and performance could be monitored, and installation damage could be examined. The design procedure involved field determining the soil undrained shear strength, often with a cone penetrometer or vane shear, and estimating the traffic wheel loading. Then the aggregate thickness was determined, with and without a layer of fabric, where the stress level at which rutting occurs was adjusted to reflect the contribution of the geotextile. This procedure and the curves developed are one of the simple methodologies still used today to determine aggregate design thickness over a layer of geotextile. Figure 4 shows early projects using geosynthetics for subgrade reinforcement over soft soils.

Today the use of a geosynthetic layer placed over a weak subgrade soil before select material or aggregate is placed is common. This is particularly useful for construction over soft spots, wet and swampy conditions, or soft soil deposits. The geotextile prevents very fine, wet soils from pumping or migrating up into the aggregate, contaminating it and reducing its strength, as well as preventing the aggregate from penetrating into the subgrade.

Geosynthetics are usually considered effective for subgrade separation when the native soils are weak, with a CBR of 3–8. In very soft soils (CBR< 3), some reinforcement can be achieved with geosynthetics by increasing the local bearing capacity and lateral restraint of the soil. Ideally a geogrid is used in combination with a geotextile layer. The strong geogrid confines the material placed on or under it and does not allow lateral movement or “shoving” of the material, while the geotextile layer acts as a filter to separate the materials.

a) A rough pioneered road

b) Geotextile over muskeg in Alaska

b)

Figure 4. Examples of a geotextile being placed over a soft subgrade soil prior to placement of aggregate.

## 3. CURRENT APPLICATIONS

Earth reinforced systems, reinforced soil slopes, geosynthetic confined soils, or MSE retaining walls, are by far the most common type of retaining structure built today. They offer an economical and cost-effective alternative to traditional gravity-type structures for most moderate height walls. For rural low-volume roads, where access may be difficult and when the budget is limited, the use of prefabricated or lightweight geosynthetic reinforcing materials, combined with local or on-site soils, such as used in MSE technology, has many advantages (Keller et al. 2011).

Reinforced soil slopes, or reinforced fills, are another cost-effective option when needing a retaining structure or to solve space constraint problems. They consist of an embankment fill built up in compacted lifts with layers of a reinforcing material such as geogrid or geotextile placed throughout the embankment. The reinforcing material adds tensile resistance to local (face) and deep-seated shear failure in the embankment. They are somewhat cheaper than a retaining structure for the same site since no facing material is involved, and construction can be relatively rapid. They do require more space since the face is on a slope versus a vertical wall face. Geogrids are most often used for reinforcement because of their superior strength.

Design and construction of MSE walls and reinforced fills is well-documented. The two-volume FHWA publication, *Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes* (Berg et al. 2009), is perhaps the most comprehensive publication regarding MSE structures. Design criteria for slope stabilization and wall reinforcement are found in this publication. These reinforcement principals are used both in "Deep Patch" fill and road shoulder stabilization, as well as in Geosynthetic Reinforced Soil bridge abutments, as described below.

## 3.1 Deep Patch Fill Stabilization

Deep patch is used as a maintenance technique to reduce or stop continual settlement in areas of an over-steep "sliver fill" slope or a settling road shoulder through inclusion of several reinforcing layers of geogrid or geotextile. It is not considered a full structural fix for a slope, but inclusion of the geosynthetic reinforcement makes a marginally unstable slope marginally stable. By using deep patches, road settlement and road maintenance costs have been reduced. The deep patch design is a shallow road-fill slope repair where the upper 1–2 meters of the subsiding section of roadway is excavated, the fill material is replaced with compacted select backfill, and several layers of geogrid or other reinforcing material are installed. Geogrid has been the most commonly used type of reinforcement, but multiple layers of closely spaced geotextile (every 150–200 mm) might offer additional cost savings to this technique for shoulder stabilization.

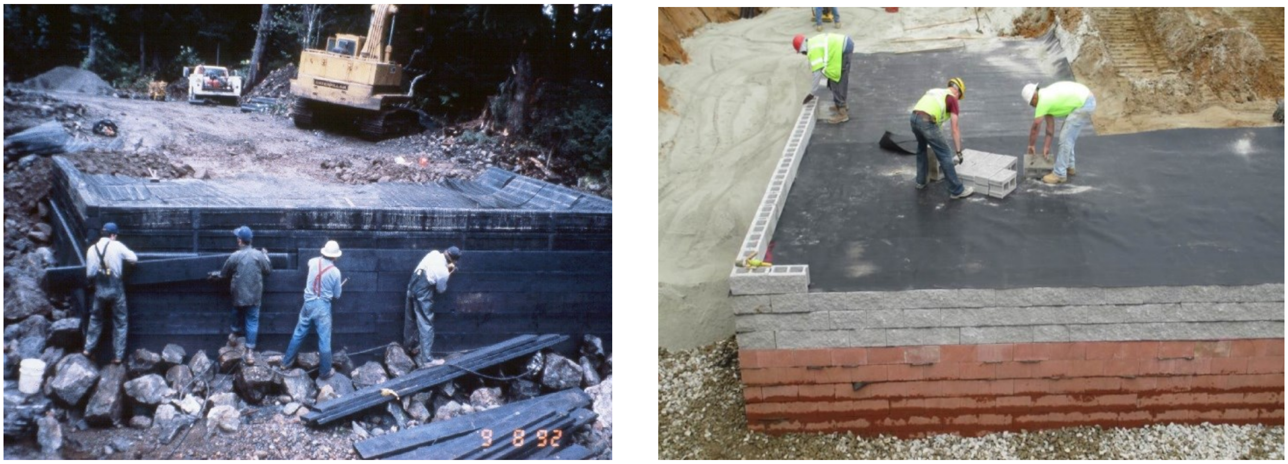
Numerous sites have been constructed to date using deep patch in the western United States with great success! The methodology has been documented in the publication *Deep Patch Road Embankment Repair Application Guide* (Wilson-Musser and Denning 2005). Additionally, research and laboratory testing are being conducted by the Federal Highway Administration (Cuehlo et al. 2012) to validate the effectiveness of this methodology and the ability of reinforcement layers to reduce the development of cracks in a slope. The FHWA methodology is more conservative than the original Forest Service design because of greater risk on their highway projects. Figure 5 shows a typical construction step of a deep patch project where backfill material is being placed on a layer of geogrid reinforcement prior to compaction of the backfill layer.

Figure 5. Construction of a deep patch road embankment repair project.

## 3.2 Geosynthetic Reinforced Soil (GRS) Bridge Abutments

Geosynthetic-reinforced soil (GRS) bridge abutments offer a desirable alternative to conventional bridge abutments in many applications, can be substantially less expensive, and can reduce construction time. GRS abutments were first used on some forest bridges in Alaska in 1990, as seen in Figure 6 (left photo), where geogrid reinforcement was used and extra timber was placed on the face to protect the wall. Today the GRS–IBS (integrated bridge system) methodology is currently being used in many Federal Highway Administration, forest, and county projects, with hundreds of GRS bridge abutments built to date. With a GRS abutment, the bridge superstructure sits on top of the geosynthetic-reinforced abutment fill. Abutment construction can typically be made using common construction equipment and, with the superstructure and abutment on the same material, differential settlement is minimized. Geotextiles have most often been used for reinforcement, and standard modular concrete blocks used for the facing elements (see Figure 6, right photo).

Information on the design and use of GRS bridge abutments can be found in the NCHRP Report 556 *Design and Construction Guidelines for Geosynthetic-Reinforced Soil Bridge Abutments with a Flexible Facing* (Wu et al. 2006) and the report titled *Geosynthetic-Reinforced Soil Integrated Bridge System Synthesis Report* (Adams et al. 2011), which provides state-of-the-practice information on design of GRS–IBS structures. Figure 6 shows construction of two GRS abutment using both geogrids and geotextile reinforcement with timbers and modular concrete blocks for wall facing.



a) Timber-faced abutment

b) Concrete block-faced abutment

Figure 6. Construction of an early timber faced, geogrid reinforced bridge abutment (left photo) and a concrete block faced, geotextile reinforced GRS-IBS abutment (right photo) (right photo courtesy of Daniel Alzamora).

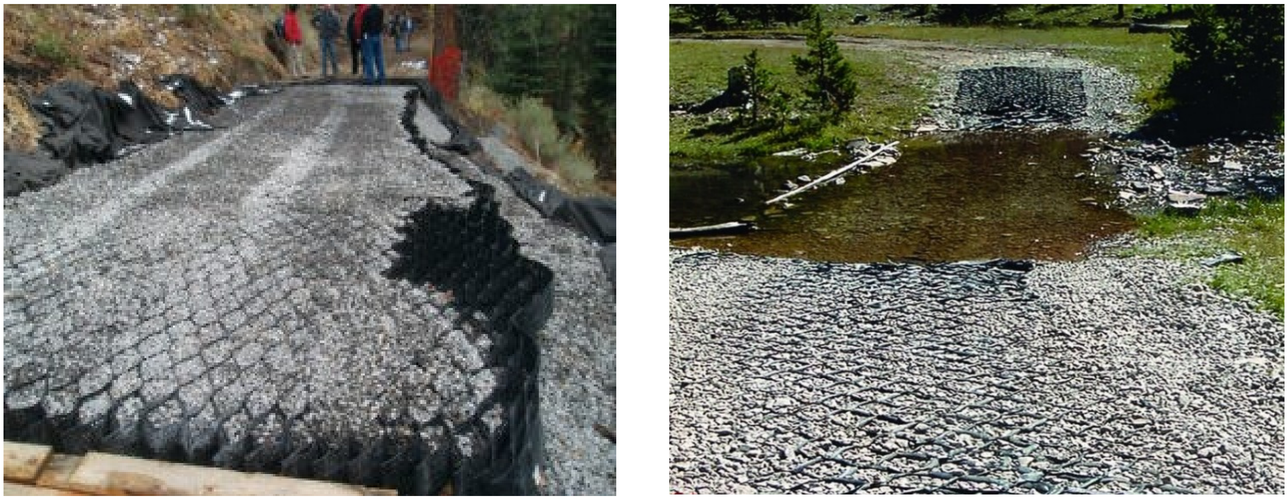
### 3.3 Geocell Uses

Geocells, or plastic cellular confinement structures, are typically made of high-density polyethylene (HDPE), are a “honeycomb” shaped structure with 150 to 200 mm diameter cells, that are usually filled with and confine sands and gravels. They commonly come in cell heights of 75, 100, 150, and 200 mm, and in expanded sheets several meters wide and 5 to 6 meters long. The collapsed sheets are relatively lightweight and can easily be transported to remote areas. They have been used in a variety of structures such as to form a confined gravel layer for subgrade support, in retaining structures, for slope protection and erosion control on raveling slopes, and as a foundation or base in low-water crossings, as seen in Figure 7. For simple fords (low water crossings), gravel-filled geocells offer a quick and cost-effective solution for reinforcing the ford driving surface through a creek (Clarkin et.al. 2006).

They have been used in Africa, the South Pacific and in India as “forms” that are filled with high-slump concrete mix to construct a roadway surface suitable for light traffic on rural roads. Their use is discussed in the publication *Cell Filled Concrete Pavement* (National Rural Roads Development Agency, Date Unknown). They have been used in pavement test sections as geocell-reinforced bases using three different infill materials: crushed limestone, quarry by-products, and Recycled Asphalt Pavement. A somewhat similar product, called “terramat”, is again made with plastic materials but is solid and have been used for temporary access over soft soils for utility lines, oil and gas sites, wind farms, etc.

### 3.4 Erosion Control Applications

Geosynthetics, or various forms of plastic, are used in a wide variety of erosion control products and measures. It is likely the fastest growing area of geosynthetic use today. Many erosion control products such as straw wattles, mats, and blankets are confined with plastic netting material. Temporary erosion control blankets and permanent lightweight geosynthetic mats are commonly used where they are placed over exposed soil on slopes to prevent erosion. Ideally many of these products have a short lifespan where exposed to the sun and are used as netting to hold organic materials such as straw or coir in place while seeds germinate under the mats. With time the geosynthetic and organic materials degrade, allowing grasses and vegetation to grow. With turf reinforcing mats (TRM), the geosynthetic is more durable and is often used to help protect and establish vegetative growth on the banks of stream channels.

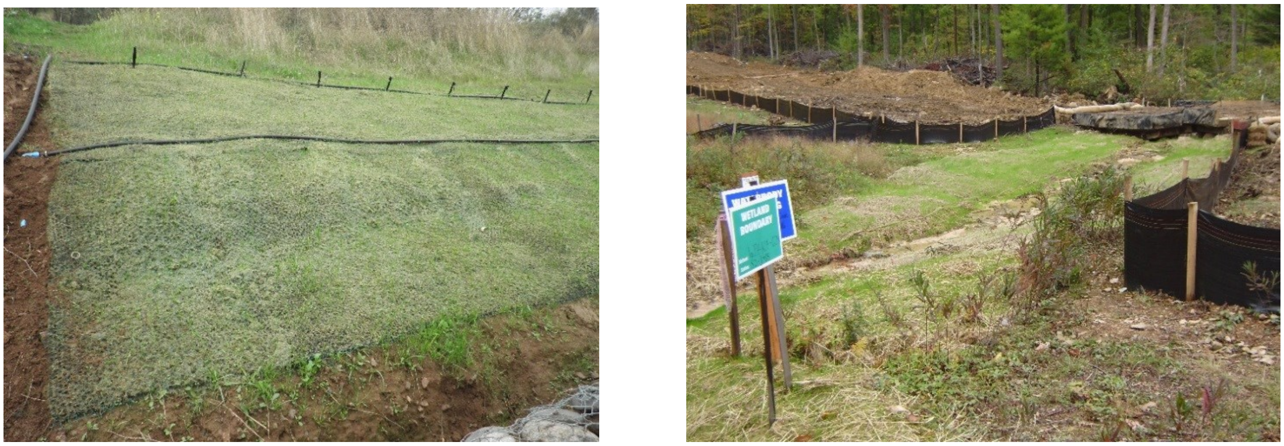


a) Geocell drainage structure

b) Geocell low-water crossing

Figure 7. Geocells used to confine gravel and provide drainage at a soft subgrade area and for a driving surface for a low-water crossing on a roadway.

Geotextile silt fences are frequently used around construction to remove suspended particles from sediment-laden runoff. They can be designed to pass through water yet act as a filter to retain the sediment. They are typically about a half-meter high, held in place with stakes, and buried into the ground in shallow trenches to prevent flow under the fence. Ideally, they should be removed once the areas have been stabilized, but they are often left in place to degrade over time. Other geosynthetic products used in drainage and erosion control include geopipe, plastic drainage channels, check dams, and drainage inlet structures. Figure 8 shows the use of an erosion control mat held together with plastic netting, and a geosynthetic silt fence around a restoration area.



a) Erosion control netting

b) Geosynthetic silt fencing

Figure 8. Geosynthetic reinforced erosion control mats (a) and a silt fence used to trap sediment and protect a restoration area (b).

## 3.5 Pavement Applications

Geosynthetic products are used a great deal today in pavements and in roadway structural sections. Geosynthetic interlayers have been used in pavement overlays for years to waterproof the pavement and as a stress-absorbing layer. Fabrics have been impregnated with asphalt to make a waterproof layer in a paved road. Stress-absorbing membrane interlayers (SAMI) are often placed before an asphalt overlay to delay or prevent reflective cracking. High-strength, low-elongation (reinforcement) paving geotextiles, such as PVC-coated, fiberglass-reinforced geogrids, have been developed to help stop reflective cracking. Figure 9 shows the placement of a high-strength, low-elongation layer on a forest road in Oregon to mitigate cracks that might reflect through the planned asphalt overlay.

A great deal of research is being done today to examine the effectiveness of including layers of geosynthetic, particularly geogrids, in the structural section to increase section strength and minimize rutting, both in paved and in gravel roads. The geosynthetic has been placed both at the base of a base layer over the subgrade, on top of the base layer, and in the base layer. Reinforcement within the layer of base aggregate, possibly in the middle, appears very effective.

a) Reinforcement placement on a road

b) Detail of the reinforcement geosynthetic

Figure 9. Placement of a high-strength, low-elongation geosynthetic layer prior to an asphalt overlay.

## 4. CREATIVE NEW APPLICATIONS

### 4.1 In-Plane Drainage

One of the most significant recent advances in use of geosynthetics for drainage has been the development of materials that provide for in-plane drainage, or otherwise lateral drainage within a geosynthetic layer, particularly in a paved road structural section. A commonly used pavement drainage system is the open-graded base course or use of an underdrain or edge drain. Providing sufficient drainage is important in mitigating pumping within the structural section since pumping often contaminates the base layer and weakens the structural section. However, conventional drainage systems rely on gravity to drain free water out of the pavement but do not drain capillary water.

New wicking geotextiles has been developed that can drain both free and capillary water under both saturated and unsaturated condition and help reduce the moisture content in the pavement structural section. The pattern of the weave of the geotextile makes it possible that both sides of the wicking geotextile absorb moisture from the surrounding soil. The multichannel shape cross-sectional area ensures the wicking fiber has a unique shape and numerous channels per fiber. These unique designs allow for the wicking fiber to generate higher capillary forces, pulling water into the deep grooved channels, and moving water along the wicking fibers. Also, these new multi-functional woven wicking geotextiles can be used for in-plane drainage as well as reinforcement, separation, and filtration.

### 4.2 Geosynthetic Use in Biotechnical Applications

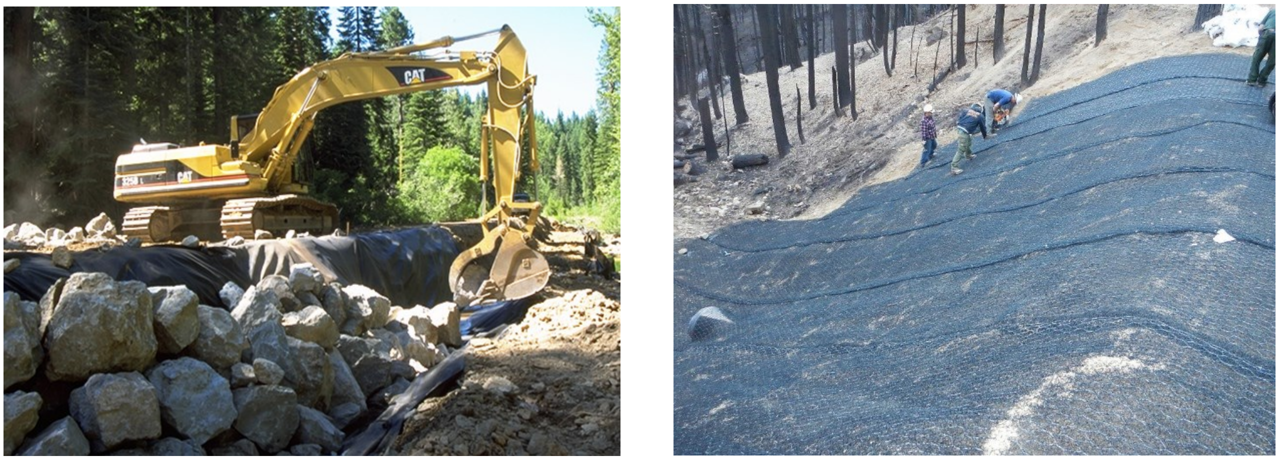
Soil bioengineering and biotechnical slope stabilization are concepts that are gaining popularity today, particularly for rural road applications in developing countries with labor-based construction methods. Vegetation is used in conjunction with other engineering materials to provide stabilization that is enhanced by the strength of vegetative roots, in conjunction with the material strength. Geosynthetic reinforced slopes have been enhanced with the inclusion of sprouting brush between each layer of geotextile or geogrid to produce a “live slope”, with the advantages of additional root strength, surficial erosion control, and a natural, vegetated appearance.

Some such structures have been called “vegetated geogrid reinforced earth buttresses”, or just “vegetated geogrids” (Gray and Sotir 1996). This technique could easily be applied to a geosynthetic “burrito” wall, where stakes of a live sprouting vegetative species could be placed at each layer interface between the soil and geotextile. Provisions would have to be made to accommodate the live stakes through the face forms.

### 4.3 Road Vulnerability Reduction Measures

With the occurrence of more frequent and more intense storms, along with increased sea-level rise and storm surges today, the concept of road resilience and reducing the vulnerability of roads to climate change impacts is extremely important. Use of geosynthetics in engineering designs contributes to that resilience in many ways. Drainage, drainage, drainage-the three most important aspects of road engineering, can be enhanced by use of geosynthetics to ensure that drainage and filtration criteria are met in underdrains, geocomposite drains, and in drainage blankets (Keller and Ketcheson 2015). A filter, typically using a geotextile, is important to be placed behind a riprap layer or gabions to provide for drainage yet prevent movement of fine soils behind the riprap (See Figure 10a).

Limited funding is always an issue when assessing risk and considering mitigation of structures from storms. Geosynthetic reinforced walls and other MSE structures are typically the least expensive type of structure available when a moderate size structure is needed. Thus, geosynthetic use is logical choice when considering some structural vulnerability reduction. Also, geocells and turf reinforcing mats have been used on culvert fill embankments in fire areas to reduce the risk of damage due to debris flows in the area from heavy rains or from overtopping if a culvert becomes plugged. Figure 10b shows a climate resilient measure involving use of a turf reinforcing mat to protect an embankment over a culvert in a forest fire area where there is risk of a debris slide plugging or damaging the culvert.



a) Geotextile filter behind riprap rock

b) Geosynthetic turf-reinforcement mat on a slope

Figure 10. Examples of two climate resilient uses of geosynthetics, as a filter in riprap installation, and using a turf reinforcing mat for protection of an embankment against debris flows or overtopping.

## 5. SUMMARY

Geosynthetic material use in low-volume rural roads have a long history of successful and cost-effective applications. Yet, their use is limited and generally under-utilized on rural roads, despite their effectiveness. A wide range of uses of geosynthetics materials for stabilization, in retaining structures, for drainage applications, and in erosion control is well documented today. Emphasis is on use in high-standard roads, but similar cost-effective opportunities exist for rural, low-volume paved and unpaved roads. The author encourages more training about the advantages of geosynthetics and more use of the many geosynthetics products in rural road construction.

Improved drainage is fundamental to the long life of a road, and effective geosynthetics use in drainage or filtration applications such as underdrains and filter blankets is well documented. Separation applications for roads over soft subgrades and to keep aggregate from becoming contaminated with fines have been used for over 40 years. Also, many creative uses of geotextiles and geogrids for reinforcement of slopes and walls have been demonstrated since the 1970s. Today "deep patch" applications for roadway shoulder reinforcement with layers of geosynthetics have proven to be very cost-effective. Finally, other current uses of geosynthetic materials in geocells, geofoam, geopipe, erosion control netting, turf reinforcement mats, and pavement reinforcement, all show ways that these materials can be cost-effective in low-volume roads.

Because of the many useful aspects of geosynthetics in engineering design, their uses as part of “engineering best practices” are valuable to make roads last their design life, be cost-effective, and help develop more resilient designs that are less vulnerable to storms in this time of climate change, both for high standard and low-volume roads.

## ACKNOWLEDGEMENTS

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