# CHAPTER 6 – PAVED AND UNPAVED ROAD SECTIONS

This chapter summarizes the following applications in roadways:

i. Reinforcement
  a. Paved Roads: Unbound Layers and Subgrade
  b. Paved Roads: Bound Layers
  c. Permanent Unpaved Roads
  d. Construction Platforms (Temporary Unpaved Roads)
ii. Moisture Barriers
  a. Frost Heave
  b. Expansive Soils
iii. Geosynthetic Clay Liners for Lining Drainage Channels

Perkins *et al.* (2005a) recently reviewed the state of practice in the United States (U.S.) regarding geosynthetic use in paving systems. Perkins *et al.* (2005a) summarized the current practices, recent developments and ongoing studies, then identified future needs for acceptance by the wider community. They divided their paper into three parts: reflective cracking, base reinforcement, and subgrade reinforcement.

Similarly, Watn *et al* (2005) reviewed the state of European practice. They looked at geosynthetics reinforcement usage in unbound and bound paving systems, then summarized recommendations and field studies. Both Perkins et al. (2005) and Watn et al. (2005) roughly separated their discussions into two categories: geosynthetics use in bound pavement layers and geosynthetics use in unbound pavement layers. Figure 15 graphically depicts where these layers are defined and the terminology used to define them.

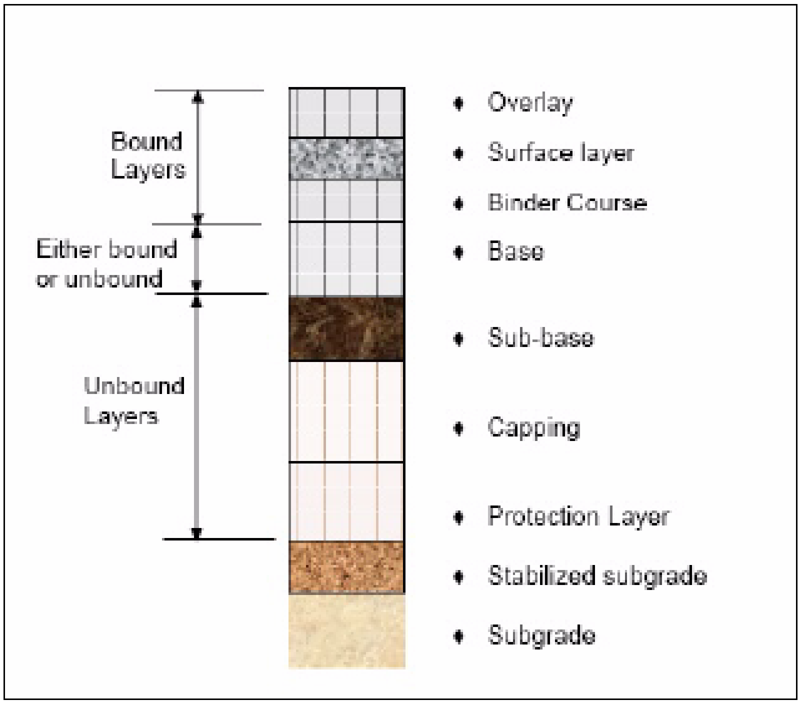

**Figure 15. Schematic. Pavement Structure Terminology (after Watn *et al.*, 2005).**

## PAVED ROADS: UNBOUND LAYERS AND SUBGRADE

### Summary of National Guidelines

AASHTO PP 46-01 (AASHTO 2001) provides guidelines for base course reinforcement by geosynthetics. It recommends following the procedures specified in Holtz et al. (1998) or the procedures from the GMA White Paper II (Berg et al., 2000). A brief description of both approaches follows.

Holtz et al. (1998) consider design methods for two types of roadways: temporary and permanent. In temporary roadway design (i.e. construction access roads, etc.), the engineer may assume the geosynthetic improves the drainage and keeps the subbase separated from the weaker native soil. This improvement is modeled by assuming an increased bearing capacity factor, which in turn reduces the required calculated thickness of the roadway. The increased bearing capacity necessitates that the assumed rut depth be large enough to mobilize this additional bearing capacity. In permanent applications, the above method can be used to reduce the thickness of any stabilizing layers, but it is assumed the reinforcement will not improve the bearing capacity of the structural layers, so no reduction in the design base course thickness is allowed. However, economies may be realized by reducing the aggregate required for stabilization and construction.

The U.S. Army Corps of Engineers (Tingle and Webster, 2003) specifies a method of design for subgrade and unpaved road reinforcement similar to that described in Holtz (1998). The bulk of these recommendations are based on the effect of geotextile separation and filtration on subgrade strength by Steward et al. (1977), although the design methodology has been expanded to include geogrids based on engineering judgment.

Berg et al. (2000) proposed a method for design of base course and subbase reinforcement based on the results of a number of field studies from literature. Base course reinforcement is quantified using three different factors: Base Course Reduction (BCR) to reduce the thickness of base courses, Traffic Benefit Ratio (TBR) to extend the life of the pavement and Layer Coefficient Ratio (LCR), which is used in some methods to match reinforced to unreinforced cross section performance by modifying the base course portion of the AASHTO structural number equation. Each factor depends on the type of reinforcement, aggregate, and design cross section for which it was calculated. Currently, however, the design approach has no mechanistic basis and the method suggests obtaining one of these ratios on the basis of lab tests that have been correlated to a field section for a particular reinforcement.

For subgrade restraint in permanent paved roads, Berg et al. (2000) recommend procedures outlined by other researchers to estimate subgrade thicknesses required to support construction activities. In these cases, the geosynthetic layer may act in one or more of the following functions: separation, filtration or reinforcement. Nine different possible design methods are listed, including the method described by Holtz et al. (1998). Seven of the remaining eight methods are for specific products calibrated by the product's manufacturer.

Berg et al. (2000) also discuss the separation and stabilization function of geotextiles in temporary and permanent roads. The geotextile acts to maintain distinct layers of base coarse and subbase materials. This prevents mixing, and at a minimum helps to ensure the designed layer thicknesses are maintained throughout the pavement's (unreinforced) design life. In many cases, the stabilization function is often primary for roadways with CBR greater than two or three.

The survey results in Chapter 3 showed that eight of 11 respondents had been involved in projects requiring subgrade reinforcement in paved roads, and that all eight also reported considering geosynthetic for these applications. Thus, there appears to be relatively strong interest in this application.

### Level of Maturity

**Developing.** A number of studies have been performed, but a mechanistic, generic, design approach that includes geosynthetic layers has not been developed. The methods suggested by Berg et al. (2000) still require calibration through laboratory and field studies, combined with local experiences. The development should be with the framework of Mechanistic-Empirical methods advocated in the NCHRP project 1-37A, revised in 1-40A-D and implemented by the FHWA. There is however a gap in the pavement design guide on how to model the use of geosynthetics in pavement structural layers.

Most of the work regarding geosynthetics in a mechanistic-empirical approach is based on finite element results. There is a need however to systematically evaluate factors controlling the pavement response when geosynthetics reinforcement is used. Such approach should include the effects of key factors such as the optimum placement of geosynthetics, the impact of reinforcement grade and types of interfaces, and the thickness of pavement layers. A possible approach to such evaluation is to use the discrete element method (DEM). The DEM can be used to characterize pavement cracking due to strain localization, and plastic strain accumulation under cyclic loading.

### Recent Advances

Unbound layers include both subgrade reinforcement and base or subbase reinforcement. The European practice described by Watn *et al.* (2005) mainly focused on the subgrade stabilization aspects, where geotextiles, geogrids and geocomposites are used to increase the bearing capacity of very soft soils. The thrust of the application is that the use of these geosynthetics reduces the pressure on the soft subgrade, and also tends to reduce deformation due to traffic or construction loading. Watn et al. (2005) observe the benefit of geosynthetic reinforcement tends to increase as the quality of the subgrade decreases or as the number of traffic loadings increase.

Perkins *et al.* (2005) also noted geosynthetics usage in the subbase to reduce deterioration and fatigue cracking due to dynamic loading. Perkins et al. (2005) stressed the importance of geosynthetics in subgrade reinforcement. This usage appears to be in practice in at least some USFS roadways, as discussed by Vischer (2003). In this case, geogrid reinforcement with a geotextile separator was used to rehabilitate a paved road over a soft subgrade. Al-Qadi and Appea (2003) also reported on an eight year study investigating the effects of geogrid and geotextile reinforcement placed between the base course and subgrade. They investigated three different base course thicknesses, and realized a measurable increase in service life and pavement quality only on the thinnest, 100 mm thick base course.

Al-Qadi's other work consisted of laboratory tests of pavement sections, some with geotextile or geogrid placed as reinforcement or as a separator over subbases with CBR ranging from two to six. (Al-Qadi et al. 1997). From this study and the ensuing field studies (Al-Qadi et al. 1998; Al-Qadi and Appea, 2003), with similar geotextile and subgrade soils, a curve was developed for design that showed the extension of service life in terms of Equivalent Single axle loads (ESALs) for a section with and without geotextile reinforcement (see also Al-Qadi, 2002). While the study did show the effectiveness of the geosynthetic in prolonging the life of a pavement before significant rutting occurred, clearly the relationship developed is dependent on the conditions represented in the field test section and the laboratory.

For subgrade stabilization, the Illinois DOT (IDOT, 2005) includes a short section on geosynthetic reinforcement of subgrade and base reinforcement. It includes a table suggesting reduced aggregate thicknesses for geotextile and geogrid -stabilized subgrade. This table should be used with caution (as is alluded to in the manual) as specific geosynthetic properties are not included with the recommendation. The manual also notes that combined separation-reinforcement action of geotextiles and geogrids have been investigated, but have generally not been cost effective in IDOT's experience.

The Washington State DOT is also currently involved in an ongoing monitoring effort for a number of roadways (Perkins *et al.*, 2005) where geosynthetics were used for subgrade stabilization. Similarly, the Wisconsin DOT has sponsored studies examining geosynthetics reinforcement of soft subgrades (Maxwell et al., 2005). From that study, it was concluded that platforms with geosynthetic reinforcement showed lower accumulated deformations than unreinforced platforms. Total deflections were always smaller for the reinforced sections compared to the unreinforced sections.

A finite element model including geosynthetics at the bottom of the unbound layer was described in Perkins and Edens (2002). The finite element mesh included models for the asphalt concrete layer, the unbound aggregate layer, the subgrade and a biaxial geosynthetic layer. This finite element model was then used in Perkins and Edens (2003), where a parametric study was performed to arrive at a set of simple design equations for flexible pavements with reinforcement between the subgrade and the unbound layer. The outcome of this design method is the calculation of ratios to estimate the increase in service life or the reduction of base course due to the inclusion of the geosynthetic. These design equations were thought to be conservative, at least within the assumptions used to develop the finite element model. Perkins and Edens (2003) also recommended further calibration as new test section results became available.

From a cost standpoint, Perkins *et al.* (2005a) observed that geosynthetics are sometimes used as a cost reduction measure, mainly by reducing the thickness of aggregate required for a project. Presumably, there is a point where the cost of aggregate saved exceeds the additional cost of the geosynthetics. Perkins *et al.* (2005a) noted a number of ongoing or past projects that have explored the benefits of geosynthetics. The U.S. Army Corps of Engineers Cold Regions Research and Engineering Lab (CRREL, 2004) was seeking funding through a pooled study to build multiple field test sections of pavement, some of which included base layer reinforcement. As of this writing (2006), the study was still awaiting funding.

## Gaps in Our Knowledge

Watn *et al.* (2005) noted that problems associated with selecting geosynthetics for use in unbound layers include:

1. Usage in this application is largely based on an agency’s prior experience or on a particular producer’s recommended empirical method.
2. Existing numerical models were largely developed to replicate field observations. Thus, key parameters for a more generally usable design methodology may be neglected simply because they are not measured or not an issue in a particular study.
3. Numerical models for pavement modeling are complicated, even without considering geosynthetics usage.
4. Modeling assumptions that will require further study include that geosynthetics a) decrease elastic deformation by increasing horizontal stresses in a soil layer, b) increase the bearing capacity of the subgrade by increasing the area influenced by the pavement, c) decrease shear stresses in the subgrade and d) reduce the deformation of the granular subbase material by confinement mechanisms.
5. The challenge of determining properties of a particular geosynthetics for a particular application that can be generalized and measured in a lab. Then, further used in a design method that properly considers the mechanism of reinforcement and the interaction between the geosynthetics and the aggregates.

Watn *et al.* (2005) concluded that the European community appears most hindered by a lack of a technically sound model for design, a lack of knowledge about the reinforcement characteristics by specifying agencies, and a lack of detailed guidance from national specifications on the subject. They note ongoing studies may help bridge the gap, but certainly more needs to be done in these areas.

Perkins *et al* (2005a) identified several issues that prevent the wider implementation of geosynthetics in pavement designs in the United States, not least of which is a rational method for cost-benefit analysis. For subgrade reinforcement, the main barriers are whether design methodologies should be formalized such that it becomes part of pavement design and just how much improvement of the subgrade affects pavement performance over the long term.

For base reinforcement, Perkins *et al.* (2005a) suggested a number of possible areas for future work. These include determining the required geosynthetics material properties and geosynthetics interaction with base aggregate, the importance of the thickness of asphalt concrete and base layer thickness for a particular reinforcement scheme, and the optimal placement of reinforcement in the base course. Other areas include interaction of geosynthetics with poor subgrades or base course aggregates, and the applicability of the design methods to rehabilitation projects.

## PAVED ROADS: BOUND LAYERS

European use of geosynthetics in bound layers is mainly limited to rehabilitation projects, according to Watn *et al.* (2005). This includes upgrading degraded gravel roads to paved roads and repaving cracked overlays. The latter appears to be the most commonly used, where the geosynthetics reduce tensile strain in the system by mobilizing tension in the geosynthetics. The use of geosynthetics also helps to minimize transfer of tension into the lower layers, which in turn retards further weakening of the previous structure.

Usage of paving fabrics in the United States is similar to European practice. Perkins *et al.* (2005a) noted that 20% of geotextiles sold are applied as an interlayer between an asphalt overlay and the original pavement surface. Both Perkins et al. (2005a) and Watn et al. (2005) note geosynthetics in the bound layers partially address problems such as frost heave, rutting and reflective cracking due to high traffic volume, cracks due to temperature variation and deformation due to soil movement. They are also sometimes used as moisture barriers or as reinforcement.

### Summary of National Guidelines

Minimum material properties for pavement overlays are discussed in both AASHTO M 288-00 and FP-03 Section 415. Design guidelines are covered by Holtz et al. (1998), which, similar to the recommendations for unbound layer reinforcement reviewed in Section 6.1.1, strongly recommend detailed pre- and post-construction field studies to determine the efficacy of the pavement overlay. Holtz et al. (1998) also suggest justifying the use of pavement overlays by considering the cost savings associated with long term maintenance, or by possible overlay thickness reduction by considering the improvement in drainage. Like bound layers, no mechanistic design methodology is covered in the national design documents.

A majority of survey respondents (seven of 11) reported being involved in overlay projects on paved roads. Of these seven, only two reported considering geosynthetics in one or more of such projects. Other respondents may have included pavement overlays in their experience of rehabilitating unpaved roads (eight of 11 respondents, six of which reported considering geosynthetics).

## Level of Maturity

**Developing.** While pavement overlays have been in use for decades, their use, or lack of use, is largely based on local experiences. The mechanisms for improvement of a pavement section with geosynthetic reinforcement are qualitatively described, but are not captured in a generally accepted design methodology.

## Recent Advances

Perkins et al.(2005a) focused on two main benefits of geosynthetics in bound layers: i) to reduce the thickness of the asphalt layer or ii) to provide a longer life compared to unreinforced asphalt overlays of the same thickness. Both Perkins et al. (2005a) and Watn et al. (2005) noted that selection of pavement overlays is largely based on local experience. Design methods are either developed by manufacturers or as empirical methods to try to quantify its function as moisture barrier or stress relief benefits.

Amini (2005) surveyed a number of field reports that described the performance of geosynthetic overlays meant to reduce reflective cracking. He concluded that, unless the asphalt overlay was very thin (on the order of 25 to 37 mm or 1 to 1.5 in thick), overlays were "very effective" at reducing reflective cracks. Amini (2005) also looked at cost effectiveness surveys in literature, noting the difficulty in identifying and assigning a cost to the benefits that may be had. He also noted that overlays tended to perform better in warmer climates, perhaps due to freeze-thaw cyclic stresses occurring in colder climates between the overlay fabric and the new pavement (instead of cracks developing from the base and reflecting into the new asphalt).

Similarly, Cleveland et al. (2002) presented the results of laboratory testing on a range of six geosynthetics used in overlays and summarized several decades of overlay research, frequently citing Barksdale (1991). Cleveland et al. (2002) describes pavement test sections that were designed, but not fully constructed or implemented by the publication date. From the lab tests, the authors observed that the inclusion of geosynthetics increased the number of cycles required before failure was reached. However, they also noted that the cost effectiveness of the fabric samples tested "appears to be marginal," based on a survey of a number of other studies.

Considering the life cycle costs of paving fabrics, Sprague (2005) developed a technique to compare the relative costs of fabrics with overlays, overlays only, and full recycling. By comparing South Carolina road records, some over the course of twenty years, Sprague (2005) concluded the cost-effectiveness of a particular application depended largely on the initial conditions of the roadway prior to application of the overlay. The roadway condition was defined by a "Pavement Condition Index," a method that is likely not measured in the same way from state to state.

Brown (2003) demonstrated that fabric and chip seal improved service life, as well as reduced the cost compared to traditional overlays with fabric only. Similarly, Davis

(2005) described the practice of combining a paving fabric with chip seal. This approach resulted in good performance in desert conditions where temperature changes can be quite large and cracking can be a concern. The first application of fabric with chip seal reported in that study was in 1987, a section that was still performing adequately when the paper was written in 2005.

Conversely, in a study for the South Dakota DOT, Storsteen and Rumpka (2000) saw no significant improvement in reflective crack occurrence or movement when either a geomembrane seal or geogrid was used between asphalt overlays and joints in existing concrete pavements. This study looked at 120 rehabilitated joints and included the approximate costs of each measure. Based on five years of observations, it was concluded that the geogrid used reflected more cracks than the sections with a geomembrane seal or no geosynthetic at all. Storsteen and Rumpka (2000)'s final recommendations included a sealed saw cut above the joints without using either geosynthetic overlay or extensive rehabilitation at the joint level.

### Gaps in Our Knowledge

From a design standpoint, both Watn *et al.* (2005) and Perkins *et al.* (2005a) noted that no model currently used for design takes into account the wide range of factors that affect the performance of asphalt pavements. Lytton (1989) proposed a model that included 13 different parameters. From Perkins *et al.*'s (2005a) perspective, the sheer number of model parameters, with their magnitudes likely changing over the length of a road project, seems to hinder implementation.

Maxim (1997) looked at 200 reports that used geosynthetics in asphalt overlays and suggested a model for design. Maxim (1997) suggested that the inclusion of a geosynthetics layer corresponded to a reduction in asphalt thickness that ranged from 25 to 45 mm (1 to 1-3/4 in). This equivalence has also been reported by Carmichael and Marienfeld (1999) and a 15 mm (0.6 in) equivalence by cost was reported by Marienfeld and Smiley (1994). The biggest challenge with citing equivalent thicknesses is that the design properties of the geosynthetics, asphalt concrete, the base course, and the subgrade are often not reported alongside the resulting equivalent thickness.

While a number of projects are ongoing (for example, NCHRP, 2005), the biggest barriers to widespread implementation comes mainly from understanding the mechanisms of the composite pavement overlay systems. Perkins *et al.* (2005a) noted that the causes of success and failure in projects with and without geosynthetics are still largely unknown. To that end, they suggested the following: i) determining the geosynthetic's primary function for a particular project, ii) understanding and modeling the entire pavement system with geosynthetics included, iii) creating a user friendly design model and, iv) developing a cost analysis to determine whether geosynthetics will be cost effective over the life cycle of a particular project. It is also imperative to address the dire need for systematic field studies to verify the design approaches and modeling results.

## PERMANENT UNPAVED ROADS

In some ways, use of geosynthetics to extend the life and improve the performance of unpaved roadway sections is similar to the unbound section of the paved roads described earlier. However, current practice tends to treat reinforcement of unpaved roads as a separate topic from paved road. This primarily comes from the lower traffic volume and acceptance of larger ruts that can develop in unpaved road applications.

### Summary of National Guidelines

AASHTO PP 46-01 (AASHTO 2001) provides guidelines for base course reinforcement by geosynthetics. It recommends following the procedures laid out in Holtz et al. (1998) or the procedures from the GMA White Paper II (Berg et al., 2000). A brief description of both approaches follows.

Holtz et al. (1998) consider design methods for permanent applications, where the bearing capacity factor, $N_c$, can be increased to reduce the thickness of any stabilizing layers, but it is assumed the reinforcement will not improve the structural layers (aggregate base course). No reduction in aggregate base course thickness is allowed. Berg et al. (2000)'s methods are not explicitly applicable to permanent unpaved roads. The methods may eventually be applied if enough field or laboratory data are collected for calibration.

In the survey, eight of 11 respondents reported being involved in unpaved roadway design, either new construction or rehabilitating of existing roads. When rehabilitating roadways, six of the eight respondents said they had been involved in a project that also used geosynthetics. New construction lagged here, with only two of eight respondents reporting geosynthetic usage. It would appear then, that unpaved road construction is a common part of the FLHD work, and that if geosynthetics use in practice can be improved or updated, potential benefits could be achieved.

### Level of Maturity

**Developing.** While the national design methods do not allow for reduced sections, geosynthetics in unpaved roads are often used in separation and filtration applications to prevent mixing of the base courses with the native soils. In the past two decades, a number of numerical studies and proposed design methods have been suggested in the literature for reinforcement applications such that smaller base course layers can be specified.

### Recent Advances

Permanent unpaved road design has appeared often in literature. Early work by Giroud and Noiray (1981) and Steward *et al.* (1977) proposed design methods that required deep and large rutting magnitudes to mobilize a tensioned membrane effect in the geotextile layer. Recently, Giroud and Han (2004a and 2004b) proposed a new empirical design model for geogrid reinforced unpaved roads, based in part on lab model tests that were reported by Gabr (2001). This model accounts for aggregate base course deterioration as the number of traffic loading cycles increase, and, while developed for a rut depth of 75 mm (3 in), allows for the input of different rut depth values, and is calibrated for a geogrid's aperture stability modulus (ASM). In their closure to the paper (Giroud and Han, 2006), defended the use of ASM, comparing traffic benefit ratios of reinforced unpaved roads measured by Watts et al. (2004) to 5% secant moduli for the geogrids used. Based on those measurements, it was noted that there was no correlation, that the average strains mobilized in the geogrids ranged from 0.1 to 1.2% and ASM is a better indicator to use in this case.

Tingle and Webster (2003) back-calculated bearing capacity factors using results from four test sections subjected to simulated traffic loading, observing rut depths up to three inches. Finite element analysis of unpaved road sections were performed by Perkins et al. (2005b) and Leng and Gabr (2002) and attempted to explain the contribution of geosynthetics to increasing the service life of the unpaved section. Leng and Gabr (2005) also presented a design model that estimates the benefits realized in an unpaved section with inclusion of reinforcement. The model includes effect of level of mobilization of subgrade bearing capacity as a function of rutting as well as relative aggregate base course to subgrade modulus ratio.

### Gaps in Our Knowledge

The recent methods proposed by Giroud and Han (2004a and 2004b) are largely uncalibrated. In their closure (2006) the authors mention that more than 20 paved road designs have since been implemented using their methods. Such database needs to be considerably increased, with long term monitoring and model verification for wide acceptance of the proposed approach.

The numerical finite element studies reported in literature may be a first step toward a more mechanistic-based design model. These methods, however, are unlikely to make their way into common practice unless (i) the interface between user and finite element model are more stream lined and user friendly, (ii) interface and material models are accepted and (iii) the results are well correlated to measured behavior. So far, the finite element studies have provided design charts that are dependent on the type of reinforcement modeled and the initial boundary conditions assumed.

## CONSTRUCTION PLATFORMS (TEMPORARY UNPAVED ROADS)

Temporary unpaved roads have different design requirements than permanent ones. Often times, they are placed simply for construction access, so the rut depths can be larger under lower number of passes by traffic (albeit heavier load). From a FLHD standpoint, these projects may also be considered within the realm of contractor design-build arrangement.

## Summary of National Guidelines

Construction platforms are not specifically covered in any national design manual. However, since they are similar to unpaved, temporary roadway reinforcement, AASHTO PP46-01, which references the GMA White Paper II (Berg et al., 2000) and Holtz et al. 1998's methods may also be used. In the latter, the geosynthetic selected is assumed to allow for reduced thickness of aggregate by improving the drainage and separation of the soil from the subbase. The model quantifies this effect by allowing a higher bearing capacity factor, $N_c$. The U.S. Army Corps of Engineers (2003) also addresses unpaved roads in a manner similar to Holtz et al. (1998).

## Level of Maturity

**Developing.** Typically, construction platforms are left to contractors to design. This would partially explain the lack of coverage in the national literature, and the low number (one) of survey respondents who said they were involved in construction platform design or construction.

## Recent Advances

Temporary work platforms are sometimes constructed over soft or very wet soils using granular fills and geosynthetics to avoid rutting and mud waves due to construction traffic. Currently, design of these platforms is based on local bearing capacity considerations, where geosynthetics tend to increase the bearing capacity factor and also attenuate the stresses transferred to the subgrade. The configuration may call for a 3D stability solution but is normally treated with a 2D plane strain model for simplicity. Often only one layer of geosynthetics is used. Perkins *et al.* (2005a) noted subgrade reinforcement for construction platforms is quite common, and usually implemented by a construction team.

The methods used to design unpaved roads can also be used for construction platforms. In this case, geosynthetics are used at an interface between soft soils and an aggregate subbase (or other granular fill). Giroud and Noiray (1981) and Steward *et al.* (1977) proposed design methods for these situations that assume the rut depth is deep enough for a tensioned membrane effect to develop in the reinforcement layer. Similarly, Leong *et al.*(2000) performed bench scale models of roadways using anchored and pretensioned geotextiles and reported the response of the composite section.

Giroud and Han (2004a and 2004b)'s empirical design model for geogrid reinforced roadways could also be used for construction platforms. In this application, the allowable rut depth should perhaps be larger and number of traffic passes should be decreased, but with heavier truck load, to account for the temporary nature of construction loading.

### Gaps in Our Knowledge

Future design methodologies should consider multiple layers of geosynthetics and their impact on reducing the thickness of the aggregate base course (ABC)m as well as limiting it deterioration with cyclic loading. Similarly, development of 3-D models such as those described by Perkins et al. (2005b) may lead to more refined results, particularly if very heavy construction loads are involved.

A wider survey of methods used by contractors on federal lands projects may also lead to a better understanding of their practice and the ability t o suggest improvements. Alternatively, more careful monitoring of the performance of temporary roadways and platforms on new projects could lead to a larger data and experience base. This could improve the confidence of construction, inspection and design personnel, and lead to improving current design methods and avoiding experiences like that reported by a survey respondent’s in Chapter 3.

## MOISTURE BARRIERS

The use of geotextiles (typically thick nonwoven needle-punched) as a capillary break is summarized by Koerner (1998). The fabric’s in-plane drainage capacity acts to cut down on the tendency of water to rise above the water table due to capillary action. If the size of the pore spaces are abruptly increased, the pore water will then tend to flow in-plane, and can be removed by underdrains. This behavior is helpful for mitigating volume changes due to ice lenses in cold weather and for stopping salt water rise in very arid regions.

Another commonly used moisture barrier, primarily in Texas and throughout the west, are geomembranes to prevent water infiltration. In these cases, water from roadways comes in contact with layers of expansive soils in the subgrade. This causes roadway heave and significantly degrades the pavement structure.

### Summary of National Guidelines

There are currently no existing national guidelines for design of capillary barriers to mitigate frost heave. The Geosynthetics manual (Holtz, 1998) does not mention their use. In the survey of FLHD and USFS engineers, one noted capillary barrier projects, and six noted they were involved in frost heave projects. Three of the six reported involvement with geosynthetics. Based on that small sample, there appears to be some demand for frost heave mitigation, and some interest in geosynthetics usage as moisture or capillary barriers. For prevention of water infiltration into expansive soils, few national guidelines are included. However, the Geosynthetics Manual (Holtz, 1998) does consider geomembranes in other barrier applications, such as landfills and containment units.

### Level of Maturity

**Undeveloped.** Some initial lab and field work has been conducted and reported in literature. Koerner (1998) recommended a design method that considers the transmissivity of the geotextiles; in fine grained soils, a secondary filtration function would also have to be considered to prevent clogging.

### Recent Advances—Frost Heave

#### *Laboratory*

In their survey of European paving technology, Watn *et al.* (2005) mentioned use of geosynthetics in frost susceptible subgrades or where old gravel roads are used as subgrade for new paved roads. In these cases, a geotextile is used to separate the frost susceptible materials from the paving layers, while geogrids are used as reinforcement. One problem, at least from the European perspective, is that it is not possible to define the benefits of using geosynthetics by performing simple tests in the laboratory.

Henry and Holtz (2001) investigated frost heave in laboratory scale test cylinders. The authors noted a few limitations to their study, including the modeled 1-D water flow, and freezing behavior, and scale effects. Nonetheless, they concluded the geotextiles used were only effective capillary barriers until moistened, particularly if soil fines had infiltrated the geotextile.

On the other hand, Henry and Holtz (2001) noted geocomposites, that is, a geonet drainage layer separated from the soil by geotextile on either side of the geonet, tended to reduce frost heave, but only when the top geotextile (between the modeled roadway and the geonet) dried out between cycles. They identify the difficulty in measuring or predicting unsaturated flow in geotextiles and the likelihood that only a portion of the geocomposite was allowing in-plane water migration.

#### *Field Studies*

Evans et al. (2002) reported the results of full scale installations of geocomposite drainage layer in roadways in Maine. The data from the study were decidedly mixed, with the authors concluding that the geocomposite was “somewhat effective in mitigating frost heave” in one of three test sections. They attributed the failure in the other two sections to the location of the water table, which during certain parts of the winter was apparently at or above the level of the geocomposite, thus circumventing the system’s function as a capillary barrier. They also noted that areas where soils were removed prior to road construction tended to heave more than areas where soils were added.

Henry et al. (2005) created test sections in two unpaved roadways in Vermont and monitored their performance over two winters. The researchers installed geotextile separators, geogrid reinforcement, capillary barriers, and geocells (a honeycomb geosynthetic that is filled with aggregate) 0.3 m (1 ft) below the cement pavement surfaces in different sections. Other methods used included edge drains or geotextile-wrapped gravel layers 0.3 m (1 ft) beneath the pavement surface to improve drainage during thaws. Henry et al. (2005) concluded that performance of the roadways were best in the sections that either provided additional strength throughout the profile (the Geocell and the cement sections), or that provided better vertical drainage and moisture control prior to freezing (the capillary barriers or the geotextile-wrapped gravel layers). The edge drains were thought to not be effective due to the relatively slow lateral drainage of water from the center of the roadway to the edges. It was also concluded that the geotextile separator and geogrid reinforcement did little to improve the upper 75 to 300 mm (3 to 12 in) of the roadway, which was saturated during the spring thaw and then most susceptible to deep rutting failures.

Other studies have investigated the use of polystyrene sheets as insulators (Kestler and Berg, 1995 and Konrad et al., 1996***).*** In this case, the polystyrene inclusion acts to interrupt the formation of ice, reducing the zone where heave can occur. Similarly, Leu and Tasa (2001) discuss practices in Minnesota, where geotextiles have been used primarily for their ability to separate sections damaged by frost boil (where fine subbase material is pushed up into the aggregate base course during thaws) from the newly placed subgrade.

### Recent Advances—Barriers for Expansive Soils

Steinberg (1998) describes in detail a number of highway and structural case studies from the American West and around the world that have used Geosynthetics to mitigate expansive soil problems. A discussion of testing, design and material costs is also presented. Basically, the geomembrane is installed as a barrier against vertical water infiltration, against horizontal water infiltration from road shoulders or other flowing ground water, or against both. The geomembrane placed has very low hydraulic conductivity, which essentially keeps the initial moisture in the expansive soil unchanged. These horizontal and vertical barriers are usually installed in tandem with drainage structures, to prevent water from ponding on the road surface and to reduce hydraulic heads leading to water infiltration.

### Gaps in Our Knowledge

The largest gaps in frost heave mitigation practice involve applying the results of the relatively few laboratory and field tests to model development and practice. There is ongoing work as to the best methods to mitigate frost heave. While geosynthetic capillary barriers are gaining some ground as a new application, specific design methods and field performance data have yet to be developed.

More controlled field testing will be required to fully quantify whether certain frost heave mitigation techniques, either as moisture barrier, capillary barrier, or both, are useful. These types of studies, however, require multi-year commitments to monitoring over a series of freeze-thaw seasonal cycles. A viable design method is also required, as are methods that will allow the costs of various possible solutions to be compared. In expansive soils, most solutions appear to be regional or on a state-by-state basis. A more systematic national effort and design methodologies is needed for wider application of this technology.

## GEOSYNTHETIC CLAY LINERS

Geocomposite Clay Liners (GCLs) are manufactured by sandwiching or embedding bentonite clay in geotextiles or attaching a layer of bentonite to geomembranes. As water comes in contact with the bentonite, the bentonite expands, effectively reducing the hydraulic conductivity and creating a barrier to flow. For drainage ditches, the GCL could be used to minimize seepage into the surrounding ground, and channeling the water to a sump area for routing to storm water facilities. GCLs can also be a key component in reducing contaminant transport from roadways into the surrounding environment, allowing non-point source contaminated run-off to be sent to a particular location for treatment instead of making its way directly into sensitive areas.

### Summary of National Guidelines

GCLs are mentioned briefly in the “barriers” section of the NHI Geosynthetics manual (Holtz et al. 1998). In that section, their usage was described as waterproofing layers in tunnels walls or bridge abutments, storm water retention pond or canal liners, and secondary containment for underground storage tanks. It is also mentioned that overlapping is generally required to create a water-tight seal.

### Level of Maturity

**Underdeveloped**. While GCLs for environmental applications (such as landfills) are well developed, the application to prevent seepage from ditches are virtually unused by the FLH. Only one of eleven respondents in the survey in Chapter 3 reported using geosynthetic clay liners in any application. This may be partly due to unfamiliarity with the material, concerns about long term performance, or a lack of more explicit guidance in design documents.

### Recent Advances

Boardman and Daniel (1996) investigated the ability of clay liners to “self heal” over many wetting and drying cycles in two geotextile-bentonite (GT-B) composites. They noted that one GT-B system developed large cracks in the bentonite when desiccated, which significantly increased hydraulic conductivity (from $10^{-9}$ to $10^{-3}$ cm/s or from approximately $10^{-10}$ to $10^{-4}$ in/s in this study) until the bentonite was rehydrated. In this test, hydration took a little over an hour. The other GT-B system did not develop such cracks during desiccation, an observation attributed to the higher reinforcement given by the particular geotextile used in the product. Lin and Benson (2000) performed a similar test, adding a calcium chloride solution and more wetting-drying cycles. They, too observed significant cracking and loss of self-healing due to the chemical change in the bentonite and the loss of its ability to self heal.

Egloffstein (2001) noted that hydraulic conductivity of GCL liners tends to increase over the first three years of the liners' life, as sodium ions in the bentonite are replaced by calcium ions in the seepage liquid. This ion replacement can increase the hydraulic conductivity by as much as one order of magnitude. In ditches near roadways or other structures to which deicing salts, such as calcium chloride, are applied this ion exchange could be of concern and would have to be considered in design. Jo et al. (2005) further observed the stronger the salt solution, the more likely an increase in hydraulic conductivity. Jo also noted the amount of time it took for GCLs exposed to salt solutions to reach a stable, higher conductivity. For weak salt solutions (< 50 mM calcium ion), an increase of around one order of magnitude in hydraulic conductivity occurred over a time period of about 0.2 years. For stronger solutions, Jo et al. (2005) observed a nearly immediate 3 order of magnitude increase in hydraulic conductivity that stayed constant thereafter.

GCL liners for canal rehabilitation in Germany were reported by Heerten and List (1990). Side slopes varied from 5 to 30 degrees, and the measured shear strength was 34 degrees, which was in part dictated by the nonwoven needling process. In this case, a soil cover was used over the GCL. Crouse et al. (2000) described procedures used to install GCL's at a mine site. The GCL was covered with rock using a scraper and belly dump. After installation and removal of the rock, visual inspection showed no observable damage to the GCL by either the rocks or the scraper.

The required overlap of GCL to overcome possible shrinkage and separation between adjoining layers was discussed by Thiel et al. (2005). They measured shrinkage due to cyclic wetting and drying and recommended overlap amounts to overcome the change in GCL panel spacing. On a related material note, Zornberg et al. (2005) compiled a database of direct shear tests on GCL to measure the GCL's internal friction angle. They determined the internal friction shear strength of a GCL varies considerably between manufacturers and the date of manufacture, and includes variability in the type of geosynthetic used and the bentonite used.

## Gaps in Our Knowledge

The research above identifies a few areas of inquiries, mainly considering the behavior of the GCLs. First, the change in hydraulic conductivity over time due to wetting and drying cycles, desiccation and salt infiltration should be better quantified. The hydraulic conductivity value will determine how much water seeps from the ditch. Second, shear strength and overlap considerations will determine survivability and constructability of the GCL liner system. These values will have to be combined with other studies of soil-GCL interface friction studies, either on the manufacturer level or on a project basis. Third is the behavior of GCL under relatively thin cover thickness as would be the case for lining ditches.

The biggest barrier however to wider GCL implementation is the increase in hydraulic conductivity that appears to occur when the bentonite comes in contact with salt solutions, resulting in cracks that will not fully self heal after desiccation due to the loss of swelling. Unless the GCL can survive such environmental hazards or the location is chosen such that the GCL remains at least partially wet or away from road or natural salt infiltration, increases in seepage will occur.

Part of the problem may be solved by using expansive clays with more calcium than sodium. While this would decrease some of the swell potential, it would reduce the ion exchange that occurs when sodium-rich bentonite is exposed to high concentrations of calcium in solution. Lee and Shackelford (2005) observed similar behavior in their work, where bentonite with higher calcium content did not show increases in hydraulic conductivity as large as higher sodium content bentonite when exposed to calcium chloride solution.

## SUMMARY

This chapter reviewed the progress of geosynthetics as applied to pavements, including reinforcement applications, moisture barriers and geosynthetic clay liners for lining ditches. In spite of the length of time geosynthetics have been used in pavement applications, there is still a lack of consensus as to their benefits. There is, however, a tremendous opportunity for future development and optimization of usage to determine the cost-effectiveness of geosynthetic in new and rehabilitation applications as described in this chapter. In the meantime, it seems the most benefit can be derived by FLHD from systematic and careful application of geosynthetics to particular projects, monitoring performance, and focusing not only on the benefits realized but also understanding the likely reasons for those benefits. These calibration efforts should be a part of the larger efforts underway by NCHRP and FHWA to develop new and refine existing design methods.

Reinforcement applications are by far the most common use of geosynthetics in paved roads, unpaved roads or construction platforms. Despite decades of laboratory and field scale testing, the available design procedures (particularly for unpaved roadways) still recommend significant field verification efforts if geosynthetics are used as part of a design. Mechanistic-empirical design methods are currently being developed for paved roadway design, as are comparative ways to determine the cost effectiveness of roadway profiles containing geosynthetics. These continuing developments should be monitored in coming few years to see if wider implementation is possible.

Moisture and capillary barriers have been implemented and studied more frequently, and are a developing technology. The use of geosynthetics to control expansive soils has mainly focused on encapsulation of the soils beneath the roadway with geosynthetics, while control of frost heave has focused on adding drainage layers or capillary barriers to prevent water from freezing in the roadway profile. On the other hand, geosynthetic clay liners run-off control are largely undeveloped for roadway applications. Further studies of their survivability and effectiveness on a field scale must be performed before they could be widely implemented and accepted in practice.