CHAPTER 7 – RECOMMENDATIONS

Work presented in this report is aimed at providing guidance and recommendations on systematically including geosynthetics in highway construction projects by Federal Lands Highway Divisions (FLHD). The recommendations are based on information from the review of the current state-of-the-art and state-of-practice literature in several target areas using geosynthetics. In addition, input from a survey collecting information on current approaches and practices of various engineers in agencies related to FLHD was considered. Target technical areas included the following:

i. Walls
ii. Slopes
iii. Deep patches for soft shoulders
iv. Reinforced soil foundations (embankments, shallow foundations)
v. Unbound pavement layers
vi. Bound pavement layers
vii. Moisture barriers
viii. Liners to control/prevent seepage

Erosion control and drainage applications of geosynthetics were mentioned within the report but not emphasized as these applications are at present considered to be sufficiently used by FLHD. Table 9 summarizes the current state of general practice within the industry and the status of the respective FLHD specifications. Table 10 summarizes the types of geosynthetics that can be used in the applications covered in this report. The proposed recommendations establish actionable items for a wider implementation of geosynthetics in construction projects by FLHD and their stakeholders. The recommendations are classified into three categories: i) Broad guidelines for specifications updating, ii) Adaptation of specific design approaches for expedient implementation of best practice technologies, and iii) System-level recommendations for further development prior to wide acceptance for a particular application.

BROAD GUIDELINES FOR SPECIFICATIONS UPDATING

It is recommended to technically update the geosynthetics guidelines used by FLHD to include design guidelines, and, in addition, update the standard specifications in light of these design guidelines. To aid in material selection beyond filtration, drainage and separation functions using geotextiles, the portions of the FP-03 “Standard Specifications” addressing geosynthetics should be updated to include a wider range of materials, including geogrids, geonets and geomembranes. The updated specifications could take a form similar to those currently in place in sections 714 and 415, where geosynthetics are categorized based on certain property types. As is currently done in overlay and separation projects, this type of upgrade would allow designers to specify required material properties for reinforcement and drainage without specifying a particular manufacturer’s product. This upgrade could be achieved by surveying a wide range of available geogrid, geonets and geotextile products for each application and determining typical ranges of material properties available on the market. An update of the standard specifications should be a **Very High** priority.

Table 9. Industry Wide Progress Toward Implementation of Projects in which Geosynthetics are Used.

Application	Level of progress/implementation					
	Technical awareness	Number of constructed projects	Existing FHWA material specifications	Standard design methods	Performance monitoring methods	Possible Implementation by FLHD
Separation	Very High	Very High	Could be improved	Mature	Mature	Should be in common use
Drainage	Very High	High	Could be improved (only textiles currently)	Mature	Mature	Should be in common use
Walls	Very High	Very High	Reinforcement needed	Mature	Mature	Should be in common use
Slopes	Very High	Very High	Reinforcement needed	Mature	Mature	Should be in common use
Deep patches	Emerging	Few	Reinforcement needed	Emerging	Improving	Proceed carefully
Embankments over soft soils	Very High	High	Could be improved	Mature	Improving	Should be in common use
Column Supported Embankments	Emerging	Moderate	None	None standard	Improving	Should be considered more often
Shallow Foundation	Low	Low	None	None	Lab scale tests	Research required

Table 9 (continued). Industry Wide Progress Toward Implementation of Projects in which Geosynthetics are Used.

Application	Technical awareness	Number of constructed projects	Existing FHWA material specifications	Standard design methods	Performance monitoring methods	Possible Implementation by FLHD
Paved Roads: Unbound Layers and Subgrade	Moderate	Moderate to High	Reinforcement specifications needed; separation OK.	Suggested, but not finalized	Multiple field tests, varying results	Implement with careful monitoring
Paved Roads: Bound Layers	Low-Moderate	High	Existing, Could be Improved	None finalized, broad rules	Variable in different areas	Implement with careful monitoring
Permanent Unpaved Roads	Moderate	Uncertain	Reinforcement specifications needed; separation OK.	Suggested, not yet finalized	Variable in different areas	Implement with careful monitoring
Temporary Unpaved Roads (Construction Platforms)	Moderate	Uncertain	Reinforcement specifications needed; separation OK.	Same as unpaved roads above	Very few projects	Implement if project falls under FLHD responsibility
Moisture Barriers	Low	Low	None	None	Very few projects	Research required
Liners to Control/Prevent Seepage	Low	Low	None	None	Very few projects	Consider for sensitive environmental issues

Table 10. Types of Geosynthetics Used in the Applications Covered in this Report.

Application	Geocomposite	Geogrid	Geomembrane	Geonet	Geosynthetic Clay Liner	Geotextile
Walls	X	X		X		X
Slopes	X	X		X		X
Deep patches for soft shoulders	X	X		X		
Embankments over soft soils	X	X		X		X
Column Supported Embankments		X				X
Shallow Foundation		X				X
Paved Roads: Unbound Layers and Subgrade	X	X		X		X
Paved Roads: Bound Layers	X	X		X		X
Permanent Unpaved Roads	X	X		X		X
Temporary Unpaved Roads (Construction Platforms)	X	X		X		X
Moisture Barriers	X		X	X	X	
Liners to Control/Prevent Seepage	X		X		X	

In addition to updating the current specifications, it seems imperative to include information on design guidance using both geotextile and geogrids in reinforcement applications. This will likely not be a part of an updated FP-03, but at least should be a recognized set of documents that will guide and standardize relatively simple designs. While design guidelines are not a complete substitute for engineering experience and judgment, they should serve as a catalyst to facilitate the implementation of geosynthetics especially in applications that are generally accepted as being state-of-practice by the profession. These include MSE walls, reinforced embankment slopes, and embankments on reinforced soil foundations. Once design guidelines are accepted and distributed to the FLHD design community, wider specifications can be written to complement the design guidelines. Development of design guidelines for applications that are considered state of practice should be a **High** priority, although it could be implemented in a piece-wise approach.

It is also recommended to consider adopting guidelines similar to those developed by HITEC (1998) to evaluate and speed acceptance of proprietary earth retaining systems. This may be as simple as using the existing HITEC reports if particular wall systems are considered. Such evaluation guidelines should include suggested design procedures and methods of construction. No such guidelines are currently available for reinforced embankment slopes or embankments on reinforced soil foundations; the development of a process similar to that adopted for reinforced walls should be considered, either in-house or as a part of a larger effort in collaboration with other agencies. Indeed, many state DOTs have lists of “approved” products for particular applications. Washington State DOT, for example, maintains a list of reinforcement geosynthetics that can quickly be approved for use in relatively simple slopes and walls in “non-aggressive” soils. The development of this type of list could be gradual as projects are approved and successful, thus the priority is **Moderate to Low**.

IMPLEMENTATION OF STATE OF PRACTICE DESIGN APPROACHES

The purpose of developing application-specific design recommendations is to assist FLHD professionals with the design of geosynthetics structures that have been repeatedly constructed over the past two decades. There are well documented design approaches for MSE walls, reinforced soil slopes, and embankments on reinforced soil foundations. The standardization of the design process of these applications will encourage FLHD professionals to perform the design and accumulate experience with the analytical approaches. In support of such effort, we recommend the following:

i. The development of charts that standardize the design of reinforced walls or slopes for configurations describing low, medium, and high categories while taking into account different backfill and foundation soil types. These charts should provide baseline design information including, for example, length of reinforcement, number of reinforcement layers, and strength of reinforcement materials, but at the same time should afford flexibility to economize a given design. It is our understanding that the FLHD does not often design (but does approve) MSE walls. As such, the priority for this project could be considered **Moderate**.

ii. The development of simple computer modules within the framework of MathCAD or Excel to aid FLHD engineers or geologists in expediently performing design and in investigating the sensitivity of the design configurations to key input parameters. While there is a computer program by FHWA for design of slopes/walls, programs for other applications are missing. For example, several modules can be developed for design of reinforced paved and unpaved roads, embankments on soft foundations, moisture barriers, frost heave mitigation, pavement overlays, shallow foundation reinforcement, and edge drainage. Providing these analysis tools to allow a degree of automation will facilitate the design and empower the designers with the flexibility of expediently discerning the best option(s) for a given project, while simultaneously allowing comparison of “traditional” design solutions. To implement geosynthetic technologies more uniformly and hopefully more easily, the priority of this recommendation could be considered **Moderate**.

iii. FLHD should adopt a series of short courses with a logical sequence to specifically emphasize applications of interest to them. Design issues of relevance to FLHD can be covered with detailed examples and case histories to empower FLHD engineers with tools to broadly use geosynthetics when appropriate. This series of educational efforts should be specifically designed and targeted toward FLHD professionals, and should be digitally recorded and distributed agency wide. While development of new courses could be given **Low** priority, in the shorter term, **Very High** priority should be given to using existing NHI courses or presentations by manufacturer’s engineers and representatives on topics of particular interest to FLHD personnel. In addition a **Very High** priority should be given to the development of installation pocket guides for geosynthetics-related construction inspection to assist field personnel.

iv. FLHD should also consider an aggressive education program for construction managers, engineers, and technicians who inspect MSE walls, reinforced soil slopes and other projects in which geosynthetics are used. Many wall failures are often attributed to poor construction control, and to some extent the success of geosynthetic implementation is dependent on knowledgeable field staff who can identify improperly installed or damaged geosynthetic materials. This could be in part accomplished through continued use of NHI courses. Priority: **Very High.**

SYSTEM-LEVEL RECOMMENDATIONS FOR FURTHER DEVELOPMENT

There are several applications that are important to the practice of FLHD but are either not well developed or their design process and implementation are not well documented in literature. Recommendations regarding each of these applications are as follows:

Deep Patches for Soft Shoulders

There are some limited cases presented in literature on the use of soft deep patches as a rehabilitation measure but work was performed mainly for the USFS. It is recommended that a comprehensive technical review of the USFS’s experience be performed to determine the likely need for further improvement or development; this step may already be underway in a forthcoming report in which the history and performance of several deep patch projects are investigated (FLHD CTIP, 2006). It is also recommended that the design approach presented by Musser and Denning (2005) should be implemented at a number of possible sites that can be instrumented or visually monitored. Once additional field data are obtained, the adequacy of this design process could be assessed and revised if needed. Thus, depending on the demand from FLHD clients and considering the activities currently underway, the priority for deployment of this technology following Musser and Denning's guidelines could be **Very High.** Once well developed and established as successful, design guidelines and personnel development should be incorporated as outlined in parts I and II of this chapter.

Column Supported Embankments

There are some prior documented examples implementing column supported embankments in the field. In addition, design guidelines are available in literature. FLHD should be implementing this technology but with the effort of monitoring and documenting the structures' performance. Key components to be developed for a wider acceptance of this technology include the following:

i. Develop guidelines for determining when the faster construction times allowed by column supported embankments are economically attractive. This could be considered to be of **Low** priority.
ii. Develop guidelines for selection of proper geosynthetics to be used in the "beam method" of design based on strength and confinement conditions. The priority here is **Low**,
iii. Review recent field studies and attempt to investigate whether a tensioned membrane or soil arching is developed and its percent contribution to the overall support mechanism. This priority is probably **Low** to FLHD, but could significantly improve the design methods currently in use.
iv. Verify numerical and analytical approaches with data from field studies to discern the differences in performance between the rigid and more flexible type of columns, and the resulting stress transfer between support columns and native soil. The priority here is also **Low,** although could be quickly implemented as a part of planned field construction.
v. Develop analytical approaches to better predict deformation (horizontal and vertical) of these systems. This priority is also probably **Low** to FLHD, but could significantly improve the design methods currently in use.

Shallow Foundations

In the case of shallow foundations on soft soils, the major advantage of using soil reinforcement is the ability to use smaller and shallower excavations. A reduction in the excavation size provides for significant cost savings and substantial health and safety benefits due to the shortening of construction and labor time, the excavation of shallower and smaller foundation pits, and the use of less natural fill material. However, there is a lack of data on the fundamental mechanics associated with the attenuation of stresses and deformation modes of geosynthetics-reinforced mats supporting shallow foundations over soft soils. It is recommended that FLHD use reinforced shallow foundations on a case by case basis. Widespread use should not be pursued at this time as there is a need for documented case studies and accumulated experience before a threshold is met for acceptance in practice. The following information is required for standardized design:

i. The definition of capacity improvement factor (CIF) as a function of deformation level due to the incorporation of reinforcement and its dependency on reinforcement type. While laboratory-generated values exist, field verification is needed before wide adoption is recommended.
ii. The definition of the stress-strain distribution within and below the reinforced soil mass for the design of the system and the evaluation of settlement (similar to methods for un-reinforced soils),
iii. The mechanics of load transfer as a function of deformation level where anisotropic material properties and membrane action of the reinforcement may play different roles, and,
iv. Life cycle cost analysis to demonstrate the advantage of using geosynthetics reinforcement versus the traditional "excavate and replace" approach in cases where both options can be employed.

Reinforcement of soil beneath shallow foundations is an emerging technology. As there are other technologies that can be adopted more immediately, the priority of this research effort is probably **Low**.

Subsurface Voids

In theory, geosynthetics reinforcement can be used to bridge geologic discontinuities including sinkholes and old mine subsidence areas. It may not, however, be sufficient to use such an approach as the sole technology in this situation, especially if future enlargement of the subsurface voids is expected (as in sinkholes for example). It is recommended to identify locations under the jurisdiction of the FLHD that could benefit from the use of reinforcement to bridge over subsurface voids. In such cases, the use of geosynthetics, in addition to other options such as grouting, should be considered. It is also highly recommended to always instrument the reinforcement geosynthetics with strain gages and other sensors to determine if failure is in progress and take additional precautions, particularly in areas where such subsidence would pose a major hazard to the public (or in high visibility areas). This approach has been used successfully in Germany for high speed rail corridors. For a wider acceptance of use of geosynthetics for bridging over subsurface voids, the following developments are needed:

i. Identification of areas under FLHD's jurisdiction that may be subject to subsurface voids, and determine if such a mitigation approach can be economical or worthwhile. Priority: **Low.**
ii. Although not directly related to geosynthetics, establishment of methods to improve the ability to predict where voids may occur, so that geosynthetics can be properly deployed. Priority: **Low.**
iii. Study of characteristics of large and small voids and the underlying geologic processes. Accordingly, the applicability of the current design methods to each should be undertaken before wide deployment of this technology is implemented. Priority: **Low.**

Unbound Road Sections

The FLHD may consider eliminating the difference in design approaches between permanent and temporary unpaved roads and consider integrating the two using the same design approach. This recommendation is based on the notion that the difference between "temporary and permanent" is inherently recognized in terms of magnitude of the rut depth, design life, and the number of traffic passes. The priority of this is probably **High.**

From a design perspective, there are analytical approaches for design of reinforced unpaved roads. There is, however, a need to build up a database of experience on the field performance of reinforced versus unreinforced sections. This can be achieved by either actively constructing or monitoring reinforced unpaved road sections as well as funding or otherwise supporting (through access to projects, for example) systematic research projects that will provide such data with analyses. Accordingly, the following recommendations are advanced:

i. Consider limited application of the Berg et al. (2000), Giroud and Han (2004) and/or Leng and Gabr (2006) methodology to one or more road sections that can be instrumented and monitored to calibrate the methods for Federal Lands' applications. After calibration is complete and some confidence in the methods established, wholesale adoption may be considered. Priority: **High.**
ii. Monitor and construct unpaved road projects so that a database of successful and unsuccessful projects can be developed and analyzed. By determining where problem areas are on a particular roadway, targeted use of geosynthetics or other technology can be more effective. The focus should then be on determining "why" a particular measure worked or did not work, not simply on "if" it produced the desire outcome. Priority: **High.**
iii. The two recommendations above will take considerable time if implemented on traditional projects. An alternative that will save time but require more of a mainstream research effort would be to use accelerated testing facilities or test tracks to get results faster. Priority: **Moderate.**
iv. Perform life cycle cost analysis to discern the impact of using geosynthetics taking into account materials and transportation cost. Priority: **High**, if sufficient data are available.

The efforts described in i through iv above will be extensive and beyond the mandate of FLHD alone. As such, FLHD should consider supporting and assisting pooled funds or other studies to help validate design approaches and move forward with wide adoption.

Paved Roads

Geosynthetics can potentially be used to enhance the performance of the pavement sections by increasing its service life, reducing rutting, and minimizing reflection cracking. The use of geosynthetics in paved roads, however, has been mainly limited to rehabilitation projects involving asphalt overlays for repair of reflective cracking and in research projects. As resurfacing work is commonly employed for the maintenance of roads, geosynthetics can be used to reduce the thickness of the resurfacing bituminous layer or to increase the life cycle of the overlay (if the same thickness is maintained.) While pavement overlays have been in use for decades, geosynthetics use in this application has largely been based on local experiences. Minimum material properties for pavement overlays are discussed in both AASHTO M 288-00 and FP-03 Section 415 but FP-03 does not include recommended design guidelines. Generally, no mechanistic design methodology is covered in the national documents. Existing methods are empirical in nature and are usually developed by manufacturers for specific products.

The mechanisms for improvement of a pavement section with geosynthetics reinforcement are qualitatively, and at times quantitatively, described in literature, but a generally accepted design methodology is not yet available. In addition, the cost effectiveness of incorporating geosynthetics in paved sections is generally unknown over the life cycle of a particular project. Accordingly, it is recommended that the following be considered:

i. Methods to quantify pre and post overlay performance should be standardized such that the results of various projects can be better compared. Priority, **Moderate** if an overlay development program is initiated and funded
ii. Mechanistic models for incorporating geosynthetics at various locations within the pavement section are needed. These models will account for the effects of different types of geosynthetics, subgrade condition, Asphalt Concrete (AC) and Aggregate Base Course (ABC) layer thicknesses, and location of the geosynthetics. Priority: **Moderate.** Other researchers are pursuing this option numerically; it may be best, therefore, to adopt a “wait and see” approach for this item.
iii. Similar to applications of geosynthetics to unbound layers, rigorous field testing and aggressive monitoring programs should be developed. This could be implemented on existing projects or through research projects at accelerated testing facilities. Priority: **Moderate**.
iv. Methods to determine economic benefit of reinforcement are needed with quantification of the overlay’s impact on life cycle, short and long term savings in reconstruction, and upfront materials cost. Priority: **Moderate**, if significant overlay programs are implemented.
v. Identification of geographic locations where the use of geosynthetics in pavement application will be the most beneficial considering environmental potential and life cycle cost. Priority: **Moderate.**

The efforts described in i through v above will also be extensive and beyond the mandate of FLHD alone. As such, FLHD should consider supporting and assisting pooled funds or other studies to help realize the proposed recommendations.

Moisture Barriers (Frost Heave/Expansive Soils)

Moisture and capillary barriers are two applications that mainly aim at reducing frost heave and shrink/swell adverse impacts on paved and unpaved roads. No federal guidelines are currently available for design of capillary barriers to mitigate heave, while some state DOTs have experience using geomembranes as barriers to mitigate shrink/swell potential. While initial lab and field studies have been conducted and reported in literature, the following is recommended before wide adoption by FLHD:

i. Document the cost effective measures (including geosynthetics as moisture barriers) to address the shrink/swell and frost heave problems. In addition to moisture and capillary barriers (in which geonet/geotextile composite seems to be the most promising product), the use of underdrains, or additional stiffening (thicker section, geocells, cement) can also serve to address frost heave. Geomembranes and ponding to initially saturate a soil appear to show promise by reducing water infiltration in shrink/swell soils. Priority: **Low** unless a specific project arises.

ii. Use principles of unsaturated flow in geosynthetics and soils to develop analytical model for the design of these systems. Priority: **Low.**

iii. Continue to support instrumented programs in a variety of soil profiles. In this case, moisture/capillary barriers can be installed in pavement sections and the structure performance of the enhanced section is compared to control sections. Data from such comparison can be used to develop the best design approach. Priority: **Low** in new projects**, High** in existing projects.

GCLs for Seepage Ditches

Only one of eleven respondents in the survey in Chapter 3 reported using geosynthetics clay liners in any application. The use of GCLs for lining seepage ditches is, however, a novel application and should be considered as an option, particularly to address non-point source pollution in environmentally sensitive areas. Areas to be developed include quantifying the change in the GCL's hydraulic conductivity over time due to wetting and drying cycles, desiccation and salt infiltration. 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 natural salt infiltration, increase in seepage flow will occur due to increase in the materials' hydraulic conductivity. For a wider implementation of this technology, the following is recommended:

i. Work is needed to determine the "strength" of salt solutions typically experienced in run-off during winter or in water infiltration in arid climates where salts leach from the soils.

ii. Accordingly, further studies are needed to determine long term hydraulic conductivity of GCLs under conditions similar to those encountered in roadway ditches. Performance data are needed under various environmental conditions (such salt spraying) in order to render such an approach viable as a ditch lining material.

iii. Effects of roots and plant growth on GCL hydraulic conductivity and integrity can be an issue that needs further investigation.

As in the case of reinforcement of soils beneath shallow foundation, this is an emerging technology. If there is an interest in pursuing it, considerable research and practical projects will be required. The priority, then, in absence of strong need driving the development, is likely **Low**.

Overall Implementation

The recommendations in the nine areas considered in this study are ambitious, and, if all or even some are implemented it would require significant human and financial resources. One recommendation that applies to all technical areas covered in this report is the return to the built structure and the collection of data on its performance (in a non-destructive or destructive manner as circumstances allow). Such performance data should be presented in context of the as-built design and lessons learned documented.

For the implementation of the recommendations put forward in this report, funding could come from a number of sources, not limited to FLHD and its client organizations. State DOTs, the FHWA, geosynthetic manufacturers, or contractors/installers could all benefit from the system level recommendations in this report, and should be approached when a promising project arises.

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