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Geosynthetics:
Specifications and Applications for Arizona, Volume 1

Arizona Department of Transportation Research Center

ADOT

Geosynthetics – Specifications and Applications for Arizona

SPR-722

Volume 1

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16. Abstract

The purpose of this Arizona Department of Transportation (ADOT) research study was (1) to update the ADOT geosynthetic specifications for geogrids, geotextiles, geomembranes, and composites; and (2) to recommend design guidelines for using geosynthetics for base reinforcement and subgrade stabilization. The study included a survey of other states regarding their material specifications for geosynthetics and their design guidelines for using geosynthetics for base reinforcement and subgrade stabilization. The study also included a review of available research, studies, and design methods for using geosynthetics for base reinforcement and subgrade stabilization. Recommended design guidelines were developed for ADOT on the basis of the review. The costs of using geosynthetics for base reinforcement and subgrade stabilization were analyzed. The analysis compared the construction costs for design alternatives with and without geosynthetics using the recommended design guidelines. The cost comparisons focused exclusively on construction costs (i.e., installed materials). There were insufficient data in the literature to develop a life-cycle cost analysis for geosynthetic use in pavements. It was determined that geosynthetics can be cost-effective for base reinforcement and subgrade stabilization. The cost savings is dependent on the design conditions, the type of geosynthetic used, and the material costs. Finally, new ADOT material specifications for geosynthetics were recommended, and revisions to the installation specifications were suggested. The recommendations were based on the results of the surveys, research, evaluations, and design guidelines developed through this project.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO — American Association of State Highway and Transportation Officials
AB — aggregate base
ABC — aggregate base course
AC — asphaltic concrete
ADOT — Arizona Department of Transportation
ADT — average daily traffic
AGC — Association of General Contractors
Alaska DOT&PF —Alaska Department of Transportation and Public Facilities
AOS — apparent opening size
APL — approved products list
ARTBA — American Road and Transportation Builders Association
ASCE-GI — American Society of Civil Engineers Geo-Institute
ASTM — American Society for Testing and Materials
BCR — base course reduction
c — subgrade shearstrength
Caltrans — California Department of Transportation
CBR — California Bearing Ratio
CFLHD — Central Federal Lands Highway Division
cm — centimeter
C&S — Contracts and Specifications (ADOT)
DCP — dynamic cone penetrometer
DOTs — Departments of Transportation
ESAL — equivalent single axle load
FAA — Federal Aviation Administration
FHWA — Federal Highway Administration
ft — foot
FWD — falling weight deflectometer
g — gram
gal — gallon
GMA — Geosynthetic Materials Association
GSI — Geosynthetics Institute
HMA — hot mix asphalt
HQ AFCEC — Air Force Civil Engineer Center
hr — hour
IGS — International Geosynthetics Society
IGSNA — International Geosynthetics Society North America Chapter
kN — kiloNewton
kPa — kilopascal
l — liter
lb — pound
LCR — layer coefficient ratio
m — meter
M_1 — subgrade modulus
MEPDG — Mechanistic-Empirical Pavement Design Guide
mg — milligram

min — minute
mm — millimeter
MPEDM — Materials Preliminary Engineering and Design Manual
MSE — mechanically stabilized earth (walls)
N — Newton
NAGS — North American Geosynthetics Society
NASA — National Aeronautics and Space Administration
NAVFAC — Naval Facilities Engineering Command
N/A — not applicable
N_C — bearing capacity factor
NHI — National Highway Institute
NTPEP — National Transportation Product Evaluation Program
oz — ounce
Pa — Pascal
PI — plasticity index
psf — pounds per square foot
psi — pounds per square inch
PSI — Pavement Serviceability Index (PSI)
Δ PSI – change in pavement serviceability index
PVC — polyvinyl chloride
QPL — qualified products list
R-Value — resistance value
sec — second
SEG — Subgrade Enhancement Geosynthetic
SEG_G — Subgrade Enhancement Geogrid
SEG_T — Subgrade Enhancement Geotextile
SN — structural number
Standard Specifications — ADOT Standard Specifications for Road and Bridge Construction
SVF — seasonal variation factor
SY — square yard
TAC — Technical Advisory Committee
TBR — traffic benefit ratio
TRB — Transportation Research Board
USACE — USArmy Corps of Engineers
UFGS — Unified Facilities Guide Specifications
USFS — USDA Forest Service
UV — ultraviolet
WES — Waterways Experiment Station
yd — yard

EXECUTIVE SUMMARY

Geosynthetics are man-made materials used to improve soil conditions, and they are most often made from petrochemical-based polymers (plastics). These materials are biologically inert and will not decompose from bacterial or fungal action. For the most part, they are chemically inert; however, some may be damaged by petrochemicals, and most have some degree of susceptibility to ultraviolet light (sunlight).

Geosynthetic materials perform five major functions in pavement and erosion control structures: they are used to provide separation, reinforcement, filtration, drainage, and moisture barriers. Current guidelines for transportation use of geosynthetics in Arizona are documented in the Arizona Department of Transportation's (ADOT) *Standard Specifications for Road and Bridge Construction–2008* (Standard Specifications), and ADOT's stored specifications. These guidelines were first developed in the late 1980s and implemented in the 1990s.

There are six families of geosynthetics: geotextiles, geogrids, geonets, geomembranes, geocomposites, and miscellaneous products. The purpose of this research effort was to update the ADOT geosynthetic specifications for four of the families: geogrids, geotextiles, geomembranes, and geocomposites. The revised ADOT specifications then would be a tool for utilizing and maximizing the benefits of current geosynthetics and would place ADOT in a better position to evaluate new developments in this field.

The first step in developing new, updated ADOT specifications for geosynthetic materials was to conduct a survey of other states regarding their geosynthetic material specifications. The objective of this survey was to identify the types of geosynthetic materials, geosynthetic design applications, and specification formats that were utilized by other states. Surveys were sent by email to all the other states in the United States. Thirty-two states responded to the survey.

The American Association of State Highway and Transportation Officials (AASHTO) has published a specification for the use of geotextiles in highways ("Standard Specification for Geotextile Specification for Highway Applications," M288). There is no consensus among the states about how to use the AASHTO M288 specification—about half the states have their own specifications and do not refer to AASHTO M288.

The most consistent state specifications refer to the current AASHTO M288, and some of the other state specifications specify reasonable properties. In other cases, specifications appear to be unreasonable or impractical for a particular application. The differences and inconsistencies among state specifications make it difficult for material manufacturers to supply proper materials. However, numerous geotextile material specifications are up to date, and these were used as a model for the updated ADOT specifications.

The second step was to review the existing ADOT specifications. The objectives of this review were to note the types of geosynthetic materials that are specified, to review the format and organization of the specifications, and to identify any references to industry specifications or test methods that may be out of date.

As part of the process for developing new specifications, the design guidelines for geosynthetics used for base or subbase reinforcement and subgrade stabilization were updated. Base or subbase reinforcement refers to the use of lateral confinement to improve the load-carrying capacity of the pavement system under repetitive traffic loadings. The reinforcement function is typically accomplished using geogrids. However, geotextiles are also used for separation in transportation applications.

The study also evaluated the cost savings of using geosynthetics in pavement. The evaluation was based on the construction costs for design alternatives with and without geosynthetics. The cost comparison focused exclusively on construction costs (i.e., installed materials). There were insufficient data in the literature to develop a life-cycle cost analysis for geosynthetic use in pavements.

Finally, updated specifications were developed on the basis of the surveys, research, evaluations, and design guidelines developed through this project. The draft specifications were written to be a complete update to Section 1014, Geosynthetics, of the ADOT Standard Specifications. The draft specifications were formatted in accordance with ADOT Contracts and Specifications (C&S) requirements.

CHAPTER 1. INTRODUCTION

The Arizona Department of Transportation (ADOT) has made a decision to revise and update specifications related to geosynthetic materials. The current ADOT specifications covering geosynthetics, including geotextiles and geogrids, were adopted in the late 1980s.

BACKGROUND AND HISTORY OF GEOSYNTHETICS

Geosynthetics are man-made materials used to improve soil conditions. Geosynthetics are most often made from petrochemical-based polymers (plastics). These materials are biologically inert and will not decompose from bacterial or fungal action. For the most part, they are chemically inert; however, some may be damaged by petrochemicals, and most have some degree of susceptibility to ultraviolet light (sunlight).

Geosynthetic materials perform five major functions in pavement and erosion control structures: separation, reinforcement, filtration, drainage, and moisture barrier. There are six families of geosynthetics—geotextiles, geogrids, geonets, geomembranes, geocomposites, and miscellaneous products:

- Geotextiles are not textiles in the traditional sense, but consist of synthetic fibers rather than natural ones such as cotton, wool, or silk.
- Geogrids are plastics formed into a very open, grid-like configuration, i.e., they have large apertures.
- Geonets are usually formed by a continuous extrusion of polymeric ribs at acute angles to one another. When the ribs are opened, relatively large apertures are formed in a netlike configuration.
- Geomembranes are thin sheets of rubber or plastic used primarily for linings and covers of liquid- or solid-storage facilities.
- Geocomposites consist of geotextile and geogrid; or geogrid and geomembrane; or geotextile, geogrid, and geomembrane; or any one of these three materials with another material.
- Other materials defy categorization, but can include threaded soil masses, polymeric anchors, and encapsulated soil cells (Koerner 2000).

In the late 1950s, Robert J. Barrett led efforts to convince engineers to use geotextiles to replace graded granular filters in erosion-control revetments. Barrett was the Vice President and Director of the Erosion Control Division for Carthage Mills. Beginning in 1958, Carthage Mills led the development, manufacture, and application of an innovative woven synthetic filter cloth, as the first alternative to costly, and largely ineffective, graded granular filters under riprap in shoreline protection. Those early plastic filter cloths eventually became known as “geotextiles.” Broader applications of these products, including roadway construction, caused the term to be broadened to “geosynthetics.” Joe Fluet, a transportation consultant, is credited with coining the term geosynthetics in 1983 (Bygness 2009).

PROJECT OBJECTIVES

ADOT developed its current geosynthetic specifications in the late 1980s. These specifications were influenced by work being performed by Joint Task Force 25, formed in 1982 by the American Association of State Highway and Transportation Officials (AASHTO), the American Road and Transportation Builders Association (ARTBA), and the Association of General Contractors (AGC). This ultimately led to AASHTO specification M288-90, published in 1990. Subsequent revisions to M288-90 (AASHTO 2007) included information on construction and installation, updated material strength requirements, and survivability. ADOT specifications do not reflect these later modifications to the AASHTO specifications (Suits and Richardson 1998).

ADOT documents its current geosynthetic guidelines in its *Standard Specifications for Road and Bridge Construction–2008* (Standard Specifications), and ADOT's stored specifications. These guidelines were first developed in the late 1980s and implemented in the 1990s (Gene Hansen, ACS Services, personal communication, September 9, 2013).

The purpose of this research effort was to update the ADOT geosynthetic specifications for geogrids, geotextiles, geomembranes, and composites. The goal was to provide ADOT with a tool for utilizing and maximizing the benefits of current geosynthetics and to place ADOT in a better position to evaluate new developments in this field.

SURVEY

The research team collected information on geosynthetic use and practices from other departments of transportation (DOTs). DOT contacts were identified from:

- AASHTO Subcommittee on Materials.
- Transportation Research Board (TRB) Committee on Geosynthetics.
- National Transportation Product Evaluation Program (NTPEP) Geosynthetics Technical Committee.
- International Geosynthetics Society (IGS) members.
- Geosynthetics Institute (GSI) members.

In addition to gathering information about other DOT geosynthetic specifications, the survey attempted to identify key DOT individuals involved with geosynthetics. Follow-up contacts by telephone or email were used to clarify information when necessary. The survey attempted to compile information on:

- The use of geosynthetics in pavements, retaining walls, reinforced slopes, and other structural elements.
- The type(s) of geosynthetics that are used in pavement system designs as well as other types of roadway or roadside cross-sectional elements and structures.
- States that use geogrids in pavement system designs and whether the geogrids are accompanied by a geotextile fabric for separation when used.
- Pavement design guidelines and design procedures used.

REVIEW OF ADOT GEOSYNTHETIC SPECIFICATIONS

The study includes a review of current ADOT geosynthetic specifications, stored specifications, special provisions, and test methods. The ADOT information was compared with similar information gathered from the survey. The ADOT information was also compared with industry and federal agency standard specifications and test methods. Sources included:

- AASHTO.
- American Society for Testing and Materials (ASTM).
- Federal Aviation Association (FAA).
- US Federal Highway Administration (FHWA).
- US Army Corps of Engineers (USACE).
- US Navy.
- FHWA Central Federal Lands Highway Division.

The research team identified out-of-date test methods and appropriate replacement test methods where applicable. The team also identified industry and federal agency standards and specifications applicable to ADOT needs.

DESIGN GUIDELINES

The research team developed design guidelines for geosynthetics used for subgrade/base reinforcement and subgrade stabilization. The process included a literature review to obtain geosynthetic performance-related study data and identify geosynthetic design techniques.

The research team used the information gathered to consider the effectiveness of geosynthetics for subgrade/base reinforcement and subgrade stabilization. These results were used to prepare geosynthetic design guidelines. The design guidelines considered different types of materials as well as different manufacturing processes. The guidelines also identified the types of geosynthetics that should be used for reinforcement and stabilization.

LIFE-CYCLE COST AND COST COMPARISON ANALYSES

The study was originally intended to develop life-cycle cost analyses for flexible pavement systems with and without geotextiles and geogrids. However, there were insufficient data in the literature to perform a life-cycle cost analysis. Therefore, the research team did not factor in potential life-cycle cost savings of using geosynthetics in the pavement section. Instead, the research team focused on a cost comparison of construction costs (i.e., installed materials). A cost analysis of the pavement design alternatives with or without geogrid and geotextile was performed to determine the economic benefit of using a geogrid and geotextile for base reinforcement and subgrade stabilization.

DRAFT SPECIFICATIONS

The research team developed draft ADOT specifications for geotextile and geogrid products based on the available research and developed associated design guidelines. The specifications address different survivability ratings, material types, and manufacturing processes. Geotextile installation specifications were included as needed. The research team also proposed industry test procedures for evaluation and acceptance of products.

CHAPTER 2: SURVEY

SURVEY OBJECTIVE

The first step in developing new ADOT specifications for geosynthetic materials was to conduct a survey of other states regarding their geosynthetic material specifications. The objective of this survey was to identify the types of geosynthetic materials, geosynthetic design applications, and specification formats that were utilized by other states. Surveys were emailed to all states in the United States except Arizona.

Individual contacts for the survey were developed from several sources. The survey was sent to the 10 DOT NTPEP Geosynthetics Technical Committee members and the five DOT members of the TRB Geosynthetics Committee (AFS70), as well as to all other state DOTs through the product evaluation listserv. If a response to these initial queries was not received from a state, a follow-up survey was sent to members of the AASHTO Subcommittee on Materials from that state. Thirty-two states responded to the survey.

The survey presented the following requests:

1. Provide an Internet link or other source for your agency's specifications related to geosynthetics.
2. Provide an Internet link or other source for your agency's list of approved geosynthetic products.
3. What types of geosynthetic materials are typically used by your agency for pavement system base reinforcement?
4. What types of geosynthetic materials are typically used by your agency for pavement system subgrade stabilization?
5. When are geogrids used?
6. When are geotextile fabrics used with geogrids for separation?
7. Has your agency conducted research or performance testing on geogrids? If so, please provide a description of the research and Internet links to any available reports.

A copy of the survey form is included in Appendix A.

SURVEY RESPONSE

The following 32 states responded to the survey.

Alabama	Missouri
California	Montana
Colorado	Nebraska
Connecticut	Nevada
Delaware	New Hampshire
Florida	New York
Georgia	North Carolina
Idaho	North Dakota
Indiana	Oregon
Iowa	Pennsylvania
Kansas	Rhode Island
Louisiana	South Carolina
Maine	South Dakota
Maryland	Texas
Michigan	Utah
Minnesota	Virginia

Of the people responding for the 32 states, 11 identified themselves as managers, supervisors, or division chiefs. The responding states covered all the geographic regions of the United States except Alaska and Hawaii. A discussion of the survey responses follows.

Query 1— Please provide an Internet link or other source for your agency's specifications related to geosynthetics.

Only Nebraska indicated that it did not have specifications for geosynthetics. The research team independently identified geosynthetic specifications for all state DOTs except Nebraska and Nevada. The Internet links to the DOT geosynthetic specifications are presented in Appendix B.

Query 2—Please provide an Internet link or other source for your agency's list of approved geosynthetic products.

In response to the second query:

- Twenty-six states provided Internet links to approved products, qualified products, or similar acceptable geosynthetic products.
- One state noted that any product that meets its specifications is acceptable.
- One state relies on AASHTO NTPEP evaluations.
- Four states did not provide an Internet link or other source for approved or qualified products.

The research team independently identified qualified or approved geosynthetic products lists for additional states besides the 32 states responding to the survey. The Internet links for the approved products lists (APLs) or qualified products lists (QPLs) for 42 states (including Arizona) were identified, as well as the link for NTPEP. Of the 42 states with APL/QPLs, Oklahoma and Utah did not list any geosynthetic products. The links for the APL/QPLs and are shown in Appendix C.

Query 3—What types of geosynthetic materials are typically used by your agency for pavement system base reinforcement?

The responses to Query 3 are summarized in Table 1 below. The detailed responses are presented in Appendix D, Table D-1.

Table 1. Summary of Geosynthetic Materials Typically Used for Pavement System Base Reinforcement

Material	List of State DOTs Using Material for Base Reinforcement (of 32 States Responding)	No. of States
Geogrids	CO, ID, IN, KS, ME, MI. MN, MO, NV, ND, RI, UT	12
Geotextile and Biaxial geogrids	CA, MN, SD, VA	4
Geotextiles	AL, DE, FL, LA, MD	5
Not typically used	CT, GA, MT, NE, NH, NY, NC, OR, PA, SC, TX	11
No response	IA	1

Query 4—What types of geosynthetic materials are typically used by your agency for pavement system subgrade stabilization?

The responses to Query 4 are summarized in Table 2. The detailed responses are presented in Appendix D, Table D-2.

Table 2. Summary of Geosynthetic Materials Used for Subgrade Stabilization

Material	List of State DOTs Using Material for Subgrade Stabilization (of 32 States Responding)	No. of States
Biaxial geogrid and/or geotextile	CA, CO, ID, IN, KS, MD, MO, MT, NE, NV, NC, ND, OR, PA, RI, SC, UT	17
Geocells	MN	1
Geotextiles	AL, CA, CO, DE, FL, GA, LA, ME, MD, MI, MT, NE, NY, NC, ND, PA, SC, SD, VA	19
Polyester, polypropylene, or polyethylene polymer	AL	1
Not typically used	CT, NH, TX	3
No response	IA	1

Query 5—When are geogrids used?

The detailed responses to Query 5 are presented in Appendix D, Table D-3, and are summarized below in Table 3.

Table 3. Summary of Use of Geogrids

Circumstance	List of State DOTs Using Geogrids for Each Circumstance (of 32 States Responding)	No. of States
With fabrics over soft soils	FL, MD, NV	3
For granular backfills	SD	1
To mitigate cracking	TX	1
In mechanically stabilized earth walls	IN, KS, ME, MO, NE, NH, NY, NC, OR, PA, RI	11
On select projects	DE, LA, VA	3
To stabilize soft subgrade	AL, CA, CO, CT, GA, IN, KS, ME, MI, MO, MT, NE, NY, NC, ND, OR, PA, RI, UT	19
For steep slope reinforcement	CA, GA, ID, KS, ME, MO, NE, NH, NC, PA, SC,	11
With aggregate base course	MN	1
No response	IA	1

Query 6—When are geotextile fabrics used with geogrids for separation?

The detailed responses to Query 6 are presented in Appendix D, Table D-4, and are summarized below in Table 4.

Table 4. Summary of Use of Geotextile Fabrics with Geogrids for Separation

Circumstance	List of State DOTs Using Geotextile Fabrics with Geogrids for Separation (of 32 States Responding)	No. of States
Depends on natural filtration	CA	1
Filter fabric between fine grained soft soils and geotextiles and aggregate above to prevent the migration of fines in to the stone matrix	AL, ME, NC, SD	4
For Geosynthetically Reinforced Soil Structure (GRSS) walls and slopes	ME, NY	2
For reinforcement and separation benefits	ID, IN, MD, RI	4
Rarely or never used	CY, DE, FL, LA, MN, NH, ND, OR, PA, SC, TX, VA	12
Soft subgrade soil encountered	CO, KS, MI, MO, NE, NV	6
Whenever geogrids are used	MT	1
Project by project basis	GA	1
No response	IA, UT	2

Query 7—Has your agency conducted research or performance testing on geogrids? If so, please provide a description of the research and Internet links to any available reports.

Of the 32 states surveyed, nine reported performing studies or testing regarding geogrids. The detailed responses to Query 7 are presented in Appendix D, Table D-5.

SURVEY ANALYSIS

The survey, along with additional research by the research team, provided important information on the use of geosynthetic products by DOTs and the application of DOT specifications to these products. Several of the queries relate to pavement design, including questions about base reinforcement, subgrade stabilization, and separation. Figure 1 is a schematic of a typical pavement cross-section.

> The surface layer is typically asphalt concrete, which is a bituminous hot-mix aggregate (HMA) obtained from distillation of crude petroleum. The asphalt concrete is underlain by a layer of base course, typically consisting of 0.2 m [meter] to 0.3 m of unbound coarse aggregate. An optional subbase layer, which generally involves lower quality crushed aggregate, can be placed under the base course in order to reduce costs or to

minimize capillary action under the pavement. The constructed layers are placed directly onto a prepared subgrade, which is generally graded and compacted natural in situ soil (Zornberg and Gupta 2010, p. 379).

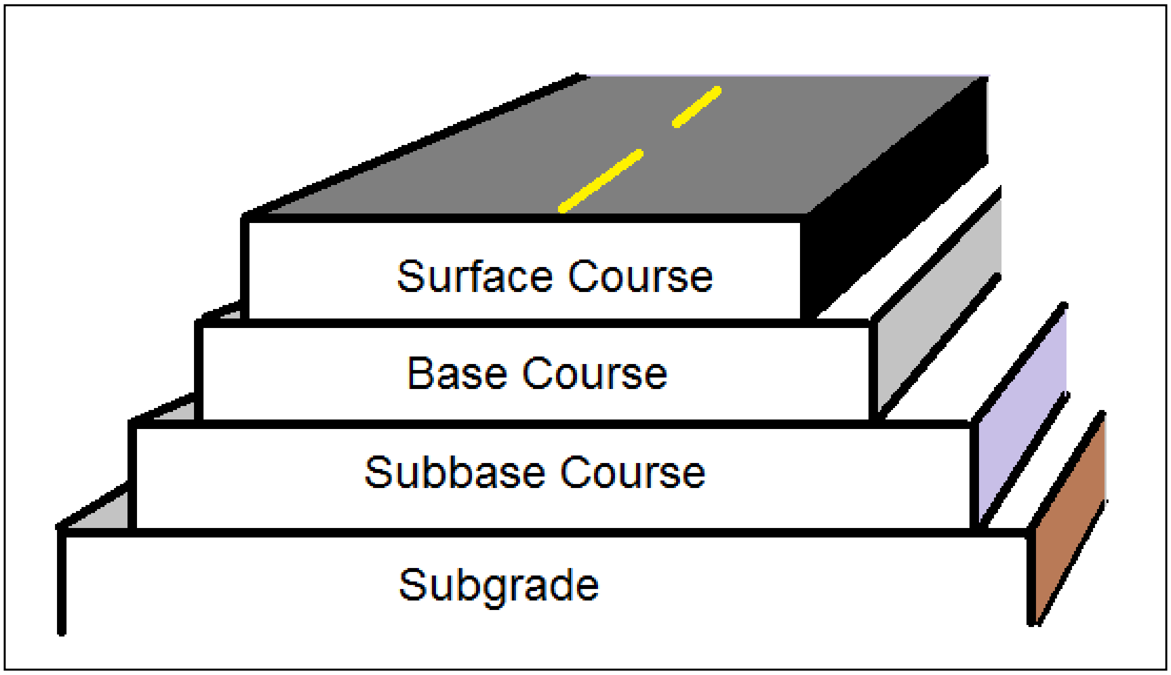

Figure 1. Schematic of Typical Pavement Cross-Section

Geosynthetics used within the pavement section can perform functions of base reinforcement, subgrade stabilization, and separation. Geosynthetics used for base reinforcement provide lateral stability and confinement to the aggregate within the base course, thereby improving the load-carrying capacity of the pavement system. Geosynthetics used for subgrade stabilization provide strength and improve load distribution to weak subgrade soils. Geosynthetics used for separation preserve the integrity of the pavement by minimizing the intrusion of subgrade soil into the aggregate base or subbase.

Geosynthetic Uses or Applications

From the review of the state specifications and the responses to Queries 3 through 6, the research team identified the following geosynthetic applications or uses identified in those specifications:

Separation

This is a common specification found in the majority of state specifications. In most cases, woven or nonwoven fabrics are allowed. The permittivity (the volumetric flow rate of water through a cross-section of a geotextile) varies, and sometimes woven slit-film fabrics are not allowed. Usually there is one strength of fabric specified, but the specified strength varies widely.

Query 6 responses state that geotextile fabrics were used with geogrids for separation by more than half the responding states. Some states indicated that the use was a project-by-project decision.

Bank Protection/Erosion Control

This is a common specification found in the majority of state specifications. In most cases, woven monofilament or nonwoven fabrics are allowed. Woven slit-film fabrics are not typically allowed. The permittivity varies, and the strength of the fabric varies. Sometimes more than one strength is specified, depending upon the size of the riprap, cushioning layer, or drop height for the riprap.

Paving Fabric

This fabric type is not widely utilized. Where it is utilized, the specification is fairly consistent throughout the states. It is typically a nonwoven fabric, but some states have specifications for alternative products. Specifications for alternative products tend to be manufacturer-oriented or related to a sole source.

Pavement System Base Reinforcement

Fabric is not typically specified for base reinforcement. Very few states have standard geogrid specifications. Typically, the geogrid specification is a special provision used on projects with a special need.

The responses to Query 3 indicate that more than half the responding states use geosynthetic materials for pavement system base reinforcement. Of these, 18 states (56 percent) use some type of geogrid for this purpose.

Pavement System Subgrade Stabilization

This is a common specification found in the majority of state specifications. Typically, the subgrade stabilization fabric is a woven fabric with low elongation, but some states also utilize nonwoven fabrics. Usually one or two fabric strengths are specified. The required permittivity is generally low. Sometimes subgrade stabilization fabrics are specified and are used interchangeably as separation fabrics.

Query 4 responses regarding types of geosynthetic materials typically used indicate that for pavement system subgrade stabilization, geogrids were the most common application of geosynthetics. Geotextiles were also reported as being used for these applications.

MSE Walls

There are very few specifications for fabric or geogrid utilized in mechanically stabilized earth (MSE) walls. Typically these fabrics are referred to in specifications for MSE walls and called out by the MSE wall supplier or designer. Many times, the specification refers to the state APL or QPL.

Reinforced Slopes

Specifications for fabrics or geogrids utilized for reinforced slopes are rare. When specified, woven fabrics with high tensile strengths are typically utilized. One state had a standard drawing specifying fabrics for reinforced slopes.

Retaining Wall

Only four states had specifications for fabrics or geogrids used in retaining wall applications. Typically, fabrics are used for modular or segmental block retaining walls (which are like MSE walls but are called retaining walls in the specifications). In a few cases, fabrics or geogrids were utilized to lower the earth pressure for a standard retaining wall.

Drainage

Almost all states specified fabrics for subsurface drainage applications. These fabrics typically were nonwoven with a high permittivity. Slit-film nonwoven fabrics were normally not allowed, but monofilament woven fabrics were sometimes allowed.

Wall Drains

Although wall drains are widely utilized behind retaining walls, not many states actually had specifications for geocomposite wall drains. Many of the states utilized strip drains instead of wall drainage boards for this application. The specifications typically specified a drainage fabric adhered to a core material of various thicknesses and strengths.

Edge Drains

Edge drains are not commonly specified. When specified, the edge drain is typically described as a core material with a fabric envelope. The thickness of the core material is usually one inch.

Silt Fence

Almost all states had a specification for silt fences. Silt-fence fabric was typically a woven fabric with low permittivity. A few states allowed nonwoven fabrics, but in most cases, the limited elongation would require a woven fabric. The fabrics were typically either supported or non-supported, which had different strength requirements.

Geogrid

Some states had geogrid specifications. Some of the geogrid specifications were for base reinforcement or subgrade stabilization. The geogrids specified for this application normally had junction strength requirements that eliminated fabric geogrids. Other states had geogrid specifications for slope reinforcement and MSE walls. These geogrids could either be punched and drawn or fabric.

Query 5 responses show that geogrids are used in a broad range of applications. These include:

- When constructing over soft soils or granular backfills.
- To mitigate cracking.
- With MSE walls.
- To stabilize or reinforce subgrade, or with a soft subgrade.
- For steep slope reinforcement.
- With the aggregate base course.

Some geosynthetic applications or uses identified in the state specifications did not match those listed in the state specification tables presented in Appendix E. If particular uses were very specific to one state and not seen in other states, they were not listed in Appendix E. In some cases, the use identified in the state specification table did not exactly match the use identified in the state specification, but it was determined from the description that the use fit into the geosynthetic application identified in the state specification table. In such cases, the specification was listed in Appendix E.

Review of State Geosynthetic Specifications

An analysis of state geosynthetic specifications was performed as part of this research. Forty-eight state specifications (all states except Arizona and Nevada) were accessed for review and evaluation. The links to these specifications are listed in Appendix B. Copies of the specifications were stored for later use in this study.

The evaluation process for the state specification was documented by completing a state specification table. Tables describing the geosynthetic specifications of the 49 states other than Arizona are presented in Appendix E. The tables include a brief summary of the specification for the state. Each state specification was reviewed to determine the geosynthetic application and uses identified. The state specification number and date was listed, the allowed geosynthetic type for each application was identified, the basis for the specification was identified, the specification was examined to determine whether design guidelines existed within the specification, and the specification was rated.

The existing Arizona specifications for geotextiles were reviewed and compared to specifications from other state DOTs. Six states were used for the comparison:

- Alaska (AK).
- California (CA).
- Idaho (ID).
- Montana (MT).
- Oregon (OR).
- Washington (WA).

See Chapter 3 for additional information on these comparisons.

Many states incorporate parts of AASHTO specification M288. This is a materials specification covering geotextile fabrics for use in subsurface drainage, separation, stabilization, erosion control, temporary silt fences, and paving fabrics. This specification sets forth a set of physical, mechanical, and endurance properties that must be met, or exceeded, by the geotextile being manufactured.

Geosynthetic Materials and Manufacturing Processes Identified

The geosynthetic materials and manufacturing processes (e.g., woven or nonwoven, slit-film fabric, monofilament nonwoven) that were allowed or prohibited for the different applications or uses were generally identified in each state specification. These are listed for each application in the state specification tables. The class or type of geotextile (depending on which material specification the state specification is based on) is listed: for example, Class A, B, or C, Classes 1 or 2, Types IA, IB, etc. Many of the specifications also had a requirement that geotextiles had to be long-chain polymeric fibers or yarns with 85 or 95 percent by weight of polyolefins or polyesters. The difference in the required percentages may be related to the original specification that the state specification was based on.

Basis of Specification - AASHTO M288

Approximately 50 percent of the state specifications were based on the AASHTO M288 geotextile specification. In most of these cases, the state specification was based on an older version of the AASHTO M288 specification and gave property values that are no longer listed in the current AASHTO M288 geotextile specification. In most cases, the states referred to the AASHTO M288 specification for some geotextile material property values, but the states usually specified their own requirements for permittivity or apparent opening size (AOS). This may be because the AASHTO specification requires gradation testing on the soil to determine what the permittivity and AOS should be, especially for subsurface drainage applications. Specifications based on the older or current AASHTO M288 specifications typically referred to the M288 geotextile class or table for the different geotextile applications rather than restating all the requirements.

The remaining states, like Arizona, did not refer at all to the AASHTO M288 specification. These states listed the material requirements for each application in separate specifications or in a large table. In many cases, the material requirements listed test methods that are no longer listed in the AASHTO M288 specifications.

Design Guidelines Within the Specifications

In most cases, state specifications did not include design guidelines. The most frequent design guideline described the selection of the permittivity and AOS of the fabric based on the actual soil gradation. In some cases, the strength of the fabric had to be based on the riprap size, the use of a cushioning layer, or the drop height for the riprap. In those cases, the project engineer had to make a decision with regard to the fabric utilized. In some cases, the California Bearing Ratio (CBR) value of the subgrade soil was used to determine the strength of the stabilization fabric to be utilized.

State Specification Presentation and Organization

The state specifications were presented in a number of different formats. Typical formats included the following:

- The state specification simply referred to AASHTO M288 for each application. No installation specifications were presented.
- The state specification had a separate specification for each application. No installation specifications were presented.
- The state specification had a specification devoted exclusively to the geotextile material requirements and separate specifications for the installation.
- The state specification had a specification with the geotextile material requirements and installation requirements all in one specification.
- The state specification presented the material property requirements for all of the geotextile uses in a large table or called out the AASHTO M288 class in the table if referring to that specification for the material requirements.
- The state specification referred to its own APL, QPL, or products approved by NTPEP.

Previous Research on the Use of Geogrids by DOTs

Responses to Query 7 regarding previous research on the use of geogrids yielded several references. Studies by the Florida Department of Transportation, Indiana Department of Transportation, Montana Department of Transportation, Oregon Department of Transportation, and Texas Department of Transportation were identified. A summary of the studies follows.

Florida Department of Transportation

The Florida Department of Transportation collected data on four test sections constructed with geogrids and geotextiles, along with a control section without geosynthetic materials. Data were collected on deflection, ride, rutting, and cracking. The study stated that long-term performance will continue to be monitored. This could provide a reference point on the benefits of geosynthetics (Florida Department of Transportation 2011).

Indiana Department of Transportation

The Indiana Department of Transportation sponsored research to evaluate the mechanical interaction between a subgrade soil and an aggregate base layer with and without a geogrid in place at the interface. A series of large-scale direct shear tests were performed to investigate the effects of geogrid properties, such as geogrid aperture area, junction strength, and tensile strength, on the interface shear strength of soil-geogrid-aggregate systems. Based on the results of the tests, an aperture area requirement and a junction strength requirement were suggested as preliminary guidelines for subgrade reinforcement systems. This research can provide reference information on the parameters measured (Lee, Choi, and Prezzi 2012).

Montana Department of Transportation

Five studies sponsored by the Montana Department of Transportation were reviewed.

Study No. 1 (Perkins 1995). This was a literature search of studies and data related to laboratory and field experimental studies, along with analytical studies related to the use of geogrid polymer materials in roadway construction. The study concluded that using data from existing laboratory or field studies was a practical approach. However, existing studies present conflicting results on improvements. Further full-scale studies were recommended.

Study No. 2 (Perkins 1999). The purpose of this study was to further establish the mechanisms of geosynthetic reinforcement as it relates to enhanced pavement performance. The study concluded that inclusion of a geosynthetic provided significant reinforcement effect.

Study No. 3 (Perkins 2001). This study produced a numerical model for unreinforced and geosynthetic-reinforced pavements. The model was designed to predict pavement durability under a variety of loading conditions.

Study No. 4 (Perkins 2002). This study evaluated geosynthetic-reinforced flexible pavement systems. The study involved two pavement test facilities. The study was intended to provide additional test section data to better define the influence of traffic loading type and geosynthetic reinforcement type. The researchers evaluated the performance of roadway test sections constructed with geosynthetics under various traffic loading conditions and geosynthetic reinforcement designs. The influence of base aggregate type and base course thickness was also studied. The study concluded that failure of some test sections was due to surface rutting induced by permanent vertical strain in the asphalt concrete, base aggregate, and subgrade layers. Asphalt cracking failures in two of the four test sections were due to delamination between the binder and surface course, due most likely to low material temperatures during paving. The study evaluated various test section monitoring techniques.

Study No. 5 (Cuelho and Perkins 2009). This study evaluated the use of reinforcement geosynthetics in unsurfaced roads constructed on soft subgrades. The research provided additional insight regarding properties that have a significant role in performance. It also offers recommendations on test procedures and protocol.

Oregon Department of Transportation

The study, *Geosynthetic Materials in Reflective Crack Prevention, Final Report, SR 537,* monitored test and control sections from 1999 to 2007. Each of the 140 test sites was revisited once each year to determine whether the cracks had reflected, and if they had, to measure their length and width. At the end of the study, comparisons were made to determine whether the geosynthetic materials were effective at controlling (by preventing or lessening the return of) reflective cracking. No conclusive data were found to demonstrate that any of the geotextile materials reduced the total number of reflective cracks (Bush and Brooks 2007).

Texas Department of Transportation

Three studies sponsored by the Texas Department of Transportation (TxDOT) were reviewed.

Study No. 1 (Button and Lytton 2007). The primary objective of this study was to investigate and develop information that will aid in evaluating the relative effectiveness of commercially available geosynthetic materials for reducing the severity or delaying the appearance of reflective cracking. The study concluded that the effectiveness of geosynthetic products in reducing the number of reflective cracks is marginal.

Study No. 2 (Prozzi and Stokoe 2007). This research evaluated the effect of geosynthetics on the pavement structural section and its resistance to environmental changes. The study involved a comprehensive scope of work, which included information survey, analytical, field monitoring, and experimental components. Each one of these components was aimed at identifying the geosynthetic properties that govern their use as reinforcement for base courses. The authors recommended that the Department geosynthetic specifications be complemented with performance properties that are relevant for design.

Study No. 3 (Prozzi and Thompson 2009). The study included an assessment of the existing literature, conducted with the objective of assessing current selection and design methodologies for the use of geotextiles in pavement applications, with particular emphasis on their suitability for conditions typical of TxDOT pavements and Texas materials and environmental conditions. Study results indicated the need for guidelines for including geotextiles in design and an educational program to get the information to working engineers.

Summary

The applications, specified fabric types, and sometimes design guidelines described by current state geotextile specifications vary widely. There is no consensus among the states about how to use AASHTO M288, since about half the states have their own specifications and do not refer to AASHTO M288. The most consistent state specifications refer to the current AASHTO M288, and some of the other state specifications specify reasonable properties. In other cases, specifications appear to be unreasonable or impractical for a particular application. The differences and inconsistencies among state specifications make it difficult for material manufacturers to supply proper materials. However, numerous geotextile material specifications are up to date, and these were used as a model for the updated ADOT specification. The ADOT installation specifications appear to be among the best and most comprehensive when compared to the other state geotextile installation specifications.

Using Information in This Chapter

The information in this chapter includes:

- References to and summaries of transportation-related geosynthetic specifications, along with evaluations of the specifications.
- Links to APLs and QPLs for geosynthetic products for transportation systems.
- Responses from state DOTs regarding the use of geosynthetic materials in transportation systems.

This information was used to evaluate current ADOT geosynthetic specifications. The content and format of the ADOT specifications were evaluated in light of the information gathered in the survey. The research team developed an outline for modifying the ADOT geosynthetic specifications.

CHAPTER 3: ANALYSIS OF EXISTING ADOT GEOSYNTHETIC SPECIFICATIONS

ANALYSIS OF EXISTING ADOT GEOSYNTHETIC SPECIFICATIONS

The second step in developing new ADOT specifications for geosynthetic materials was to review the existing ADOT specifications. The objectives of this review were to identify the types of geosynthetic materials that are specified, to review the format and organization of the specifications, and to identify any references to industry specifications or test methods that may be out of date.

Recommended changes to the specifications are noted after the review of each specification and the referenced test methods. These recommendations are based on such factors as industry trends and new industry specifications and draw from observations made in the survey of other state specifications. (See Chapter 2.)

ADOT GEOSYNTHETIC SPECIFICATIONS

This review focused on the ADOT Standard Specifications. The existing ADOT Standard Specifications are organized with material specifications separate from the installation and application specifications. Material specifications for geosynthetic materials are contained in ADOT Standard Specifications, Section 1014. The material specifications identify requirements for material properties and associated test methods. The installation and application specifications for the different geosynthetic products are contained in the ADOT Standard Specifications.

ADOT also has standard drawings, stored specifications, design manuals and procedures, and materials testing manuals and procedures that may provide guidance on the use of geosynthetic materials. These references include the following:

- ***Materials Policy and Procedure Directives Manual*.** The ADOT *Materials Policy and Procedures Manual* (ADOT 2013a) is intended to establish uniform policies regarding materials for construction projects. The current version includes 24 policy and procedure directives.
- ***Materials Testing Manual*.** The purpose of the ADOT *Materials Testing Manual: Sampling and Testing Procedures* (ADOT 2014a) is to standardize sampling and testing procedures in the various laboratories that test materials for conformance to ADOT specifications.
- ***Preliminary Engineering and Design Manual*.** The ADOT *Preliminary Engineering and Design Manual* (ADOT 1989) incorporates the *1986 AASHTO Guide for Design of Pavement Structures* (AASHTO 1986), adapted to ADOT's experience and practice, and also for the soil and climate conditions found in Arizona.
- ***Construction Manual* (no date).** The *Construction Manual* (ADOT 2011) presents a compilation of administration practices and inspection procedures. It does not replace or supersede the Standard Specifications, Project Plans, Special Provisions, or other contract documents. The *Construction Manual* is intended to be a supplement to common contract requirements.

- ***Structure Detail Drawings.*** The ADOT Bridge Group has developed a series of structure detail drawings (http://www.azdot.gov/business/engineering-and-construction/bridge/structure-detail-drawings/overview) intended to supplement contract structure drawings for bridges and appurtenant highway structures. These drawings provide standards for the details for construction of select features used in Arizona highway structures.

Method of Review

Each geosynthetic material identified in the ADOT Standard Specifications, Section 1014, is discussed and summarized in this chapter. The review of specifications is broken into four sections: geotextile specifications, geocomposite specifications, geogrid specifications, and geomembrane specifications. Geotextiles include pavement fabric, separation fabric, bank protection fabric, temporary silt fences, and drainage fabric. Geocomposites include edge drains and wall drains.

The material specifications for each type of geosynthetic identified in Section 1014 were reviewed. The current Arizona specifications were compared to other organization and state DOT specifications. The objectives of this comparison included the following:

- Determine the properties and test methods that are specified.
- Determine the number of strengths or survivability classes that are specified.
- Identify test methods that may be outdated.
- Identify types of products that are allowed or prohibited.
- Identify properties and values for which there is agreement between states and agencies.
- Identify properties for which states and agencies prefer to specify unique requirements.

In the comparison, references are made to AASHTO M288. AASHTO M288 is a widely recognized industry specification. Several states and agencies use AASHTO M288 as a basis for some or all of their specifications.

AASHTO M288

In 1982, government and industry recognized the growing use of geotextiles in road construction. As a result, the AASHTO Committee on Materials joined with ARTBA and the AGC to form Joint Task Force 25 (TF 25). The task force included representatives of the geotextile industry, private contractors, and state and federal transportation agencies. The initial focus was to review geotextile standards proposed by FHWA. The task force then published recommended geotextile specifications in the AASHTO specification book as Specification M288 on Geotextiles (Suits and Richardson 1998).

Over the years, the M288 specification has been revised to reflect experience and technical knowledge gained in the field of geotextiles. The latest version of M288 was published in 2006 (M288-06).

Review of Federal Agency Geosynthetic Standards

In Chapter 2, state specifications for geosynthetics were reviewed. Several federal agencies also maintain standards related to the use of geosynthetic products in transportation construction. The most prominent are FHWA, the US Forest Service (USFS) and a combined group under the Unified Facilities Guide Specifications (UFGS). These agency standards were reviewed to identify specifications that may be applicable to Arizona's needs. UFGS represents a joint effort of the USACE, the Naval Facilities Engineering Command (NAVFAC), the Air Force Civil Engineer Center (HQ AFCEC), and the National Aeronautics and Space Administration (NASA).

FHWA geosynthetic standards have been adopted by the USFS and Central Federal Lands Highway Division (CFLHD). Operating as part of the Office of Federal Lands Highway, CFLHD serves the transportation engineering needs of federal land management agencies in Arizona, California, Colorado, Hawaii, Kansas, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah, and Wyoming. The FHWA specifications for geotextiles were used for comparison in the review of Arizona geotextile specifications. (Summaries of the FHWA-CFLHD-USFS specifications and the UFGS specifications are presented in Appendix F.)

GEOTEXTILE SPECIFICATIONS

Arizona currently has material specifications for five types of geotextiles:

- Pavement Fabric (ADOT 1014-2)
- Separation Geotextile Fabric (ADOT 1014-4)
- Bank Protection Fabric (ADOT 1014-5)
- Temporary Silt Fence Fabric (ADOT 1014-8)
- Drainage Fabric (ADOT 1014-9)

All of these specifications are modified by ADOT Stored Specification 1014FAB (12/14/09).

The existing Arizona specifications for each of these types of geotextiles were reviewed and compared to specifications from other states and agencies. Six states were used for the comparison:

- Alaska (AK).
- California (CA).
- Idaho (ID).
- Montana (MT).
- Oregon (OR).
- Washington (WA).

These states were selected because they all have well developed specifications for these types of products and have similar soil and construction issues as Arizona. Two organizations were also used for the comparison: AASHTO and FHWA. AASHTO was selected because the AASHTO M288 specification is a basis for several state specifications and also for manufacturer product line development. FHWA was selected because FHWA has a specification that is similar to AASHTO's but that refers to some of the older ASTM test methods that the current Arizona specifications refer to.

The comparison showed that several of the states and FHWA use AASHTO M288 as a basis for their specifications, particularly for the elongation and strength requirements. For permittivity and AOS, there was more variation among states and more deviation from AASHTO requirements. For UV stability, California and Arizona specified higher performance than AASHTO specifies for some types or applications of geotextiles.

Properties and Test Methods

The following properties and associated test methods are referenced in the discussion of geotextiles and their specifications. These properties are commonly identified when specifying requirements for geotextile products. ASTM D4439, *Standard Terminology for Geosynthetics,* lists definitions and descriptions for many of these properties.

Elongation (ASTM D4632).

Elongation describes how much the geotextile stretches under tensile loading. Elongation is typically measured at the breaking or maximum load. Elongation is expressed as a percent. ASTM D4632, *Standard Test Method for Grab Breaking Load and Elongation of Geotextiles*, is the test method specified for determining elongation.

Geotextile Strength Classes.

The geotextile strength classes refer to the survivability strength classes described in AASHTO M288**,** where Class 1 is high strength, Class 2 is moderate strength, and Class 3 is low strength. The geotextile strength class determines requirements for grab strength, sewn seam strength, puncture strength, and tear strength.

Grab Strength (ASTM D4632).

Grab strength refers to the breaking tensile strength of the geotextile as measured in a grab test. A grab test is a tensile test where only a part of the width of the test specimen is gripped with clamps and the specimen is stretched until it breaks. The grab strength is expressed in units of force, Newtons (N) or pounds (lb). ASTM D4632 is the test method for determining grab strength.

Sewn Seam Strength (ASTM D4632).

Sewn seam strength refers to the breaking tensile strength of a sewn seam joining two sections of geotextile. Sewn seam strength is measured by the grab test. Sewn seam strength is expressed in units of force, Newtons or pounds. ASTM D4632 is the test method for determining sewn seam strength.

Tear Strength (ASTM D4533).

Tear strength refers to the relative tear resistance of a fabric. Tear strength is measured by the trapezoid tear method. Tear strength is expressed in units of force, Newtons or pounds. ASTM D4533, *Standard Test Method for Trapezoid Tearing Strength of Geotextiles*, is the test method for determining tear strength. The trapezoid tearing strength test is useful for estimating the relative tear resistance of different fabrics or the tear resistance of different directions in the same fabric. The trapezoid tear method produces tension along a reasonably defined course such that the tear propagates across the width of the specimen.

Puncture Strength (ASTM D6241 and ASTM D4833).

Puncture strength refers to the force required for an object to puncture or penetrate a geotextile. Puncture strength is expressed in units of force, Newtons or pounds. There are two test methods identified for puncture strength: ASTM D4833 and ASTM D6241. ASTM D6241, *Standard Test Method for the Static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm Probe*, was developed specifically for geotextiles and geotextile-related products. ASTM D4833, *Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products*, was developed for geomembranes and related products. AASHTO M288 references ASTM D6241, which is considered in the geotextile industry to be the current, accepted test method. Some state DOTs have moved to ASTM D6241, while others, including ADOT, still specify ASTM D4833.

Burst Strength (ASTM D3786).

Burst strength refers to the pressure required to burst a geotextile using a pneumatic diaphragm bursting test. Burst strength is expressed in units of pressure, either Pascals (Pa) or pounds per square inch (psi). ASTM D3786, *Standard Test Method for Bursting Strength of Textile Fabrics—Diaphragm Bursting Strength Tester Method*, is the test method for determining burst strength; however, ASTM D3786 is no longer considered to be an accepted test method in the geotextile industry. Some state DOTs, including Arizona, still specify burst strength in accordance with ASTM D3786, but AASHTO M288 no longer specifies burst strength.

In Situ Soil Passing (AASHTO T88).

In situ soil passing identifies the gradation or particle size of the soil. In situ soil passing is associated with a specific opening size or sieve. In situ soil passing is expressed as the percent of the soil (by weight) passing or going through the opening size or sieve. AASHTO T88, *Standard Method of Test for Particle Size Analysis of Soils*, is the test method for measuring soil gradation. The soil gradation is important for specifying geotextile properties such as **p**ermittivity and AOS.

Permittivity (ASTM D4491).

Permittivity refers to the volumetric flow rate of water through a cross-sectional area of geotextile in the direction normal or perpendicular to the geotextile. Permittivity is expressed in units of per second (sec^{-1}). ASTM D4491, *Standard Test Methods for Water Permeability of Geotextiles by Permittivity*, is the test method for determining permittivity.

ADOT Standard Specification Section 1014 identifies Arizona Test Method 730 as the test method for measuring permittivity. ADOT Stored Specification 1014FAB (12/14/09) updates the test method for permittivity to ASTM D4491, and AASHTO M288 references ASTM D4491.

AOS (ASTM D4751).

AOS refers to the largest soil particle size that could pass through an opening in a geotextile. AOS is expressed in dimensions of opening size, millimeters (mm) or Sieve No. ASTM D4751, *Standard Test Method for Determining Apparent Opening Size of a Geotextile*, is the test method for determining AOS.

UV Stability (ASTM D4355).

Ultraviolet (UV) stability refers to the tensile strength retained by a geotextile after UV exposure for a specified amount of time. UV stability is typically measured after 500 hours of exposure. UV stability is expressed as a percent, comparing the strength after exposure to the strength of a control specimen. ASTM D4355, *Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus*, is the test method for determining UV Stability.

PAVEMENT FABRIC SPECIFICATIONS (STANDARD SPECIFICATION 1014-2)

Arizona currently has a specification for pavement fabric; however, Arizona does not use pavement fabric. Current Arizona pavement fabric requirements are similar to AASHTO M288 requirements, although the Arizona specification has a lower grab strength requirement than AASHTO M288 does. The Arizona specification also identifies a minimum and maximum value for the mass per unit area and specifies a minimum and maximum fabric thickness.

Appendix G lists the pavement fabric specifications for AASHTO, FHWA, and each of the state DOTs that were used for comparison with Arizona specifications. The following list describes the pavement fabric specifications for AASHTO, FHWA, and each of the comparison state DOTs.

- **AASHTO** M288 has one type of pavement fabric.
- **FHWA** requirements for pavement fabric are similar to AASHTO M288 requirements. FHWA requires a greater grab strength than AASHTO M288 does.
- **Alaska** specifications follow AASHTO M288 for pavement fabric.
- **California** requirements for pavement fabric are similar to AASHTO M288 requirements. California specifications require a greater grab strength and a higher melting point than AASHTO M288 does.
- **Idaho** does not have a specification for pavement fabric.

- **Montana** does not have a specification for pavement fabric.
- **Oregon** requirements for pavement fabric are equivalent to AASHTO M288 requirements. Oregon specifications do not identify a requirement for mass per unit area.
- **Washington** does not have a specification for pavement fabric.

Observations

AASHTO, FHWA, Alaska, California, and Oregon have specifications for pavement fabric. Alaska and Oregon specifications follow AASHTO M288. FHWA, California, and Arizona specifications are similar to AASHTO M288 with a few changes. Idaho, Montana, and Washington do not have specifications for pavement fabric.

Recommendation

Arizona does not currently use pavement fabric and has no plans to use it in the future. However, other Arizona agencies do use pavement fabric, and many of these agencies also rely on the ADOT specification for pavement fabric. Therefore, Arizona should keep the specification for pavement fabric and update it in accordance with AASHTO M288.

SEPARATION FABRIC SPECIFICATIONS (STANDARD SPECIFICATION 1014-4)

Arizona has four strengths of separation fabric. The strengths are similar to AASHTO M288 Classes 1+, 1, 2, and 3. The Arizona specification identifies one permittivity and AOS requirement for separation fabric. The Arizona requirement for permittivity is higher than AASHTO M288's. The Arizona specification identifies a minimum and a maximum AOS and has a higher UV stability requirement than does AASHTO M288. The Arizona specification does not identify a requirement for sewn seam strength. The specification references older test methods ASTM D4833 (for puncture strength) and ASTM D3486 (for burst strength) instead of the newer test method ASTM D6241 (for puncture strength). The Arizona specification specifies woven and nonwoven fabric for separation. It calls for geotextiles manufactured from fibers consisting of long-chain polymers, such as polypropylene, polyethylene, and polyester.

The following paragraphs describe the separation fabric specifications for AASHTO, FHWA, and each of the comparison state DOTs. Appendix H lists the separation fabric specifications for AASHTO, FHWA, and each of the state DOTs used for comparison with Arizona specifications.

AASHTO M288 (Table 3 – Separation Geotextile).

AASHTO M288 has four strengths of geotextiles for separation, although requirements are not identified for Class 1+. AASHTO M288 identifies one permittivity and AOS requirement. AASHTO M288 has a special tear strength requirement for Class 2 woven monofilament geotextiles.

FHWA (Table 714-2 – Separation Geotextile).

FHWA has three strengths of separation geotextile. The strengths are equivalent to AASHTO M288 Classes 1, 2, and 3. FHWA identifies one permittivity and AOS requirement, which is the same as AASHTO M288 requirements. FHWA references older test methods ASTM D4833 (for puncture strength) and ASTM D3486 (for burst strength) instead of the newer test method ASTM D6241 (for puncture strength). FHWA calls for long-chain, synthetic polymers composed at least 95 percent by mass of polyolefins or polyesters to manufacture the geotextile or the threads used to sew the geotextile.

Alaska (729-2.01 – Separation Geotextile).

Alaska specifications follow AASHTO M288 for separation geotextiles, except that they call for a higher permittivity.

California (88.102B – Filter Fabric).

California specifications have a single strength of filter fabric, similar to AASHTO Class 2. California specifications have three classes of filter fabric, each with a different permittivity and AOS requirement. California specifications require greater UV stability than AASHTO M288 does. The specifications allow only nonwoven fabric manufactured from polyester, polypropylene, or combined polyester and polypropylene.

Idaho (718.07 – Subgrade Separation Geotextile).

Idaho specifications have two strengths of separation geotextile. Idaho specifications identify the lesser strength as low to moderate survivability and the greater strength as high survivability. The strengths are similar to AASHTO M288 Classes 2 and 3. Idaho specifies the same permittivity and AOS requirements as AASHTO M288 does. Idaho has a special permittivity requirement and no AOS requirement for a separation geotextile that will also be used for drainage. Idaho specifications do not identify requirements for UV stability. Idaho specifications call for nonwoven or woven geotextiles for separation. Only nonwoven geotextile can be used when the separation geotextile also functions in a drainage application.

Montana (716.02 – Separation Geotextile).

Montana specifications have two strengths of separation geotextile, moderate survivability and high survivability. The strengths appear to be equivalent to AASHTO M288 Classes 1 and 2. Montana specifications identify one permittivity and AOS requirement, which is the same as AASHTO M288's requirements. Montana references older test method ASTM D4833 for puncture strength instead of the newer test method ASTM D6241. Montana specifications call for geotextiles manufactured from fibers consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters.

Oregon (Table 02320-4 – Subgrade Separation Geotextile).

Oregon specifications have a single strength of separation geotextile. The strength appears to be equivalent to AASHTO M288 Class 3. Oregon specifications identify one permittivity and AOS requirement; the Oregon permittivity requirement is greater than AASHTO M288's requirement. Oregon does not identify a requirement for sewn seam strength. Oregon specifications call for geotextiles manufactured from fibers consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters.

Washington (9-33.2 – Table 3-Geotextile for Separation).

Washington specifications have a single strength of separation geotextile. The strength appears to be equivalent to AASHTO M288 Class 2. Washington specifications have the same permittivity, AOS, and UV stability requirements as AASHTO M288 does. Washington specifications call for geotextiles manufactured from fibers or yarns consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters.

Table 5 summarizes some of the key properties and trends for separation fabric.

Table 5. Separation Fabric Summary/Analysis

Property	Specification/Requirement	AASHTO/FHWA/State DOTs
Elongation (%)	<50, ≥50	AASHTO, FHWA; AK, ID, MT, OR
	15-50, ≥50	WA
	≥50	CA
	15-115 (woven), 45-115 (non-woven)	AZ
Geotextile Strength Classes	Other Very High	AZ
	AASHTO Class 1 High	AASHTO, FHWA Type II-A; AK, MT
	Other High	ID Type II, ID Type III, AZ
	AASHTO Class 2 Moderate	AASHTO, FHWA Type II-B; AK, CA, MT, WA
	Other Moderate	AZ
	AASHTO Class 3 Low	AASHTO, FHWA Type II-C; AK, ID Type I, OR
	Other Low	AZ
Sewn Seam Strength	Specified	AASHTO, FHWA; AK, MT, WA,
	Not Specified	AZ, CA, ID, OR
Puncture Strength	ASTM D6241	AASHTO; AK, CA, ID, OR, WA,
	ASTM D4833	FHWA; AZ, MT
Burst Strength	ASTM D3786	FHWA; AZ
Permittivity (sec^{-1})	0.02 min.	AASHTO, FHWA ID Type II; MT
	0.05 min.	AK
	0.07 min.	AZ
	0.70 min.	ID Type III
AOS [mm (Sieve No.)]	0.60 (30) max.	AASHTO, FHWA; AK, MT
	0.42 (40) max.	CA Class A
	0.25 (60) max.	CA Class B, ID Type I
	0.21 (70) max.	ID Type II, CA Class C
	0.11-0.60 (140-30)	AZ
UV Stability (%)	Not Specified	ID
	50 @ 500 hours	AASHTO, FHWA; AK, MT, OR, WA
	70	AZ
	70 @ 500 hours	CA

sec^{-1}: per second   mm: millimeter

Observations

- **Elongation.** Four states, AASHTO, and FHWA specify requirements for less than 50 percent and greater than or equal to 50 percent. Washington specifies requirements for 15-50 percent and greater than or equal to 50 percent. California specifies requirements for elongation greater than or equal to 50 percent only. Arizona lists specifications for 15-115 percent (woven) and 45-115 percent (nonwoven).

- **Geotextile Strength Classes.** The strength class determines the requirements for grab strength, sewn seam strength, puncture strength, and tear strength. Only Arizona specifies a very high separation fabric class. AASHTO, FHWA, and two states specify AASHTO M288 Class 1 (high). Arizona and Idaho specify a high-strength fabric with different strength requirements than those of AASHTO M288 Class 1. AASHTO, FHWA, and four states specify AASHTO M288 Class 2 (moderate). Arizona specifies a moderate strength fabric with different strength requirements than those of AASHTO M288 Class 2. AASHTO, FHWA, and three states specify AASHTO M288 Class 3 (low). Arizona specifies a low strength fabric with different strength requirements than those of AASHTO M288 Class 3.
- **Sewn Seam Strength.** AASHTO, FHWA, and three states specify this property. Four states do not specify this property.
- **Puncture Strength.** AASHTO and five states specify ASTM D6241 as the test method for measuring puncture strength. FHWA, Arizona, and Montana specify ASTM D4833 as the test method.
- **Burst Strength.** Only Arizona and FHWA specify a requirement for this property and test method.
- **Permittivity.** Permittivity requirements vary by entity. Four different permittivity values are identified among the specifications in the comparison. Idaho has two different types of fabric, each with its own permittivity.
- **AOS.** AOS requirements vary by entity. Five different AOS values are identified among the specifications in the comparison. Two states have specifications for more than one type or class of fabric, each with its own AOS. Arizona is the only state that identifies a minimum AOS.
- **UV Stability.** Idaho does not specify a requirement for UV stability. AASHTO, FHWA, and four other states require 50 percent at 500 hours. California requires 70 percent at 500 hours. Arizona also requires 70 percent but does not identify the number of hours.

Recommendations

The following changes and updates are recommended for the Arizona specifications for separation geotextiles:

- **Elongation.** Revise elongation to less than 50 percent for woven fabric and greater than or equal to 50 percent for nonwoven fabric to align with AASHTO M288.
- **Geotextile Strength Classes.** Consolidate to three (high, moderate, and low) strengths of separation fabric. Align fabric strengths with AASHTO M288 Classes.
- **Sewn Seam Strength.** Arizona does not need to require sewn seams for separation fabric. Typically, fabric overlaps of 24 inches are utilized according to the installation requirements in Standard Specification Subsection 208-3.04.

- **Puncture Strength.** Update the puncture strength requirement to refer to ASTM D6241 instead of ASTM D4833. ASTM D6241 is the test method that AASHTO M288 has adopted for puncture strength.
- **Burst Strength.** Eliminate the burst strength requirement. AASHTO M288 does not identify requirements for this property or test method.
- **Permittivity.** Maintain permittivity as defined by ADOT. Permittivity is a property that state DOTs appear to tailor to local conditions. Specify a minimum permittivity of 0.07 sec^{-1}.
- **AOS.** Maintain AOS as defined by ADOT. AOS is a property that state DOTs appear to tailor to local conditions. Specify a maximum AOS of 0.22 mm (Sieve No. 70).
- **UV Stability.** Specify UV stability requirement at 50 percent in accordance with AASHTO M288. Specify the number of hours as 500.

BANK PROTECTION FABRIC SPECIFICATIONS (STANDARD SPECIFICATION 1014-5)

Arizona specifications currently have a single strength of bank protection fabric that appears to be similar to AASHTO M288 Class 1. Arizona identifies one permittivity and AOS requirement but does not identify a requirement for sewn seam strength. Arizona specifications reference older test methods ASTM D4833 (for puncture strength) and ASTM D3486 (for burst strength) instead of the newer test method ASTM D6241 (for puncture strength). The specifications allow only woven monofilament fabric or nonwoven fabric for bank protection. Arizona specifications call for geotextiles manufactured from fibers consisting of long-chain polymers such as polypropylene, polyethylene, and polyester.

The following paragraphs describe the bank protection fabric specifications of AASHTO, FHWA, and each of the comparison state DOTs. Bank protection fabric is also called erosion control fabric or riprap fabric. Appendix I lists the bank protection fabric specifications for AASHTO, FHWA, and each of the state DOTs used for comparison with Arizona specifications.

AASHTO M288 (Table 6 – Permanent Erosion Control)

AASHTO M288 has two strengths of geotextiles for permanent erosion control. AASHTO M288 calls for Class 2 for woven monofilament geotextiles and Class 1 for all other types of geotextiles. Woven, slit-film geotextiles are not allowed. AASHTO M288 has three sets of permittivity and AOS requirements for permanent erosion control geotextiles. The applicable permittivity and AOS are based on in situ soil grain size analysis.

FHWA (Table 714-4 – Permanent Erosion Control)

FHWA has two strengths of permanent erosion control geotextile. The strengths are similar to AASHTO M288 Classes 1 and 2. FHWA has three sets of permittivity and AOS requirements, which are the same as AASHTO M288 requirements. FHWA references older test methods ASTM D4833 (for puncture strength) and ASTM D3486 (for burst strength) instead of the newer test method ASTM D6241 (for puncture strength). FHWA calls for long-chain, synthetic polymers composed at least 95 percent by mass of polyolefins or polyesters to manufacture the geotextile or the threads used to sew the geotextile.

Alaska (729-2.02 – Erosion Control)

Alaska specifications follow AASHTO M288 for geotextiles for permanent erosion control.

California (88-1.02I – Rock Slope Protection Fabric)

California specifications have two strengths of fabric for rock slope protection. Class 10 is higher strength than AASHTO M288 Class 1 (nonwoven), and California Class 8 is similar to AASHTO M288 Class 2 (nonwoven). California specifications do not specify sewn seam strength, tear strength, puncture strength, or burst strength for this type of fabric. California specifications have one permittivity and AOS requirement for each class; the permittivity is different for the two classes, but the AOS is the same for the two classes. California specifications have a higher UV stability than AASHTO M288 does. California specifications call for nonwoven, needle-punched geotextile made from polyester, polypropylene, or combined polyester and polypropylene.

Idaho (718.06 – Riprap/Erosion Control Geotextile)

Idaho specifications have two strengths of erosion control geotextile. Idaho specifications identify the lesser strength as low-to-moderate survivability and the greater strength as high survivability. The Idaho strengths are not equivalent to AASHTO M288 classes. Idaho specifications do not have different strength requirements for woven versus nonwoven geotextiles. The specifications call for an elongation greater than or equal to 15 percent. Idaho specifications identify one permittivity requirement but do not identify a maximum AOS or a minimum UV survivability requirement for the high survivability strength. Idaho specifications call for nonwoven or monofilament woven geotextiles for erosion control. Slit-film or slit tape geotextiles are not accepted for erosion control.

Montana (716.05 – Permanent Erosion Control Geotextile)

Montana specifications have two strengths of permanent erosion control geotextile: moderate survivability and high survivability. The strengths appear to be equivalent to AASHTO M288 Class 1 and Class 2. Montana specifications have three sets of permittivity and AOS requirements, which are different from AASHTO M288 requirements. The applicable permittivity and AOS are based on in situ soil grain size analysis. The specifications reference older test method ASTM D4833 for puncture strength instead of the newer test method ASTM D6241. Montana specifications call for geotextiles manufactured from fibers consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters. Woven slit-film geotextiles are not allowed for permanent erosion control.

Oregon (Table 02320-2 – Riprap Geotextile)

Oregon specifications have two strengths of riprap geotextile. The strengths appear to be equivalent to AASHTO M288 Classes 1 and 2. Oregon specifications identify one permittivity and AOS requirement but do not identify a requirement for sewn seam strength. Oregon specifications call for geotextiles manufactured from fibers consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters. Woven slit-film geotextiles are not allowed for riprap geotextile.

Washington (9-33.2 – Tables 4 and 5-Geotextile for Permanent Erosion Control)

Washington specifications have two strengths of erosion control geotextile. The strengths appear to be equivalent to AASHTO M288 Classes 1 and 2. Washington specifications have three sets of permittivity and AOS requirements, which are different from AASHTO M288's requirements but the same as Montana's. Washington specifications call for geotextiles manufactured from fibers or yarns consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters.

Table 6 summarizes some of the key properties and trends for bank protection and erosion control fabric. Observations about Table 6 are discussed by property following the table.

Table 6. Bank Protection Fabric Summary/Analysis

Property	Specification	AASHTO/FHWA/State DOTs
Elongation (%)	<50, ≥50	AASHTO, FHWA; AK, ID, MT, OR
	15-50, ≥50	WA
	≥50	CA
	≥15	ID
	15-115	AZ
Geotextile Strength Classes	AASHTO Class 1 High	AASHTO, FHWA IV-A, FHWA IV-B, FHWA IV-C; AK, MT, OR, WA
	Other High	CA Class 10, ID Type II, AZ
	AASHTO Class 2 Moderate	AASHTO, FHWA IV-D, FHWA IV-E, FHWA IV-F; AK, CA Class 8, MT, OR, WA
	Other Moderate	ID Type I
Sewn Seam Strength	Specified	AASHTO, FHWA; AK, MT, WA
	Not Specified	AZ, CA, ID, OR
Puncture Strength	ASTM D6241	AASHTO; AK, ID, OR, WA
	ASTM D4833	FHWA; AZ, MT
Burst Strength	ASTM D3786	FHWA; AZ
Permittivity (sec^{-1})	0.1 min.	AASHTO, FHWA IV-C, FHWA IV-F; AK
	0.2 min.	AASHTO, FHWA IV-B, FHWA IV-E; AK, MT Class C, WA Class C
	0.4 min.	MT Class B, WA Class B
	0.5 min.	AZ, ID, OR
	0.7 min.	AASHTO, FHWA IV-A, FHWA IV-D; AK, CA Class 10, MT Class A, WA Class A
	1.0 min.	CA Class 8
AOS [mm (Sieve No.)]	Not Specified	ID Type II
	0.43 (40) max.	AASHTO, FHWA IV-A, FHWA IV-D; AK, MT Class A, OR, WA Class A
	0.30 (50) max.	ID Type I
	0.25 (60) max.	AASHTO, FHWA IV-B, FHWA IV-E; AK, MT Class B, WA Class B
	0.22 (70) max.	AASHTO, FHWA IV-C, FHWA IV-F; MT Class C, WA Class C
	0.15-0.21 (100-70) max.	CA
	0.11-0.60 (140-30) max.	AZ
UV Stability (%)	Not Specified	ID Type II
	50 @ 500 hours	AASHTO, FHWA; AK
	70 @ 150 hours	ID Type I
	70	AZ
	70 @ 500 hours	CA, MT, OR, WA

sec^{-1}: per second   mm: millimeter

Observations

- **Elongation.** Four states, AASHTO, and FHWA specify elongation for less than 50 percent and greater than or equal to 50 percent. Washington specifies 15-50 percent and greater than or equal to 50 percent. California specifies greater than or equal to 50 percent. Idaho specifies greater than or equal to 15 percent. Arizona specifies 15-115 percent.
- **Geotextile Strength Classes.** The strength class determines the requirements for grab strength, sewn seam strength, puncture strength, and tear strength. AASHTO, FHWA, and four states specify AASHTO M288 Class 1 (high) or equivalent. Arizona and two other states specify a high-strength fabric with different strength requirements than those of AASHTO M288 Class 1. AASHTO, FHWA, and five states specify AASHTO M288 Class 2 (moderate) or equivalent. Idaho specifies a moderate fabric strength with different strength requirements than those of AASHTO M288 Class 2. AASHTO, FHWA, and the other six states have specifications for two different classes of fabric for bank protection/erosion control.
- **Sewn Seam Strength.** AASHTO, FHWA, and three states specify this property. Four states do not specify this property.
- **Puncture Strength.** AASHTO and four states specify ASTM D6241 as the test method for measuring puncture strength. FHWA, Arizona, and Montana specify ASTM D4833 as the test method.
- **Burst Strength.** Only Arizona and FHWA specify a requirement for this property and test method.
- **Permittivity.** Permittivity requirements vary by AASHTO, FHWA, and state DOT. Six different permittivity values are identified among the specifications in the comparison. AASHTO, FHWA, and three states have three types or classes of fabrics, each with a different permittivity value to account for different soil gradations.
- **AOS.** AOS requirements vary among AASHTO, FHWA, and state DOT. Six different AOS values are identified among the specifications in the comparison. AASHTO, FHWA, and three states have more than one type or class of fabrics, each with their own AOS. Only Arizona and California identify a minimum AOS.
- **UV Stability.** Idaho does not specify a requirement for UV stability. AASHTO, FHWA, and one other state require 50 percent at 500 hours. Idaho requires 70 percent at 150 hours. Four states require 70 percent at 500 hours. Arizona also requires 70 percent but does not identify the number of hours.

Recommendations

The following changes and updates are recommended for the Arizona specifications for bank protection and erosion control geotextiles:

- **Elongation.** Revise the elongation requirement to greater than or equal to 50 percent (for nonwoven fabric) to align with AASHTO M288. Do not allow woven fabrics for bank protection.

- **Geotextile Strength Classes.** Maintain high strength of bank protection fabric. Align fabric strengths with AASHTO M288 Class 1 requirements.
- **Sewn Seam Strength.** Arizona does not need to require sewn seams for bank protection fabric. Typically, fabric overlaps of 24 inches are utilized according to the installation requirements in Standard Specifications Subsection 913-3.02.
- **Puncture Strength.** Update puncture strength requirement to refer to ASTM D6241 instead of ASTM D4833. ASTM D6241 is the test method that AASHTO M288 has adopted for puncture strength.
- **Burst Strength.** Eliminate the burst strength requirement. AASHTO M288 does not identify requirements for this property or test method.
- **Permittivity.** Update the permittivity value to 0.7, the highest permittivity value of the three values specified by AASHTO M288. This value was discussed with the technical advisory committee (TAC) and selected by the committee to account for Arizona soil conditions.
- **AOS.** Update the AOS value to 0.22 mm (Sieve No. 70), the smallest AOS value of the three values specified by AASHTO M288. This value was discussed with the TAC and selected by the committee to account for Arizona soil conditions.
- **UV Stability.** Specify the UV stability requirement at 50 percent in accordance with AASHTO M288. Specify the number of hours as 500.

TEMPORARY SILT FENCE FABRIC SPECIFICATIONS (STANDARD SPECIFICATION 1014-8)

Arizona requirements for temporary silt fences are similar to AASHTO M288 requirements for unsupported silt fences with less than 50 percent elongation. Arizona specifications have a lower grab strength requirement for the machine direction than AASHTO M288 does. Arizona specifications call for a nonwoven or a woven fabric consisting only of long-chain polymeric filaments such as polypropylene or polyester.

The following paragraphs describe the temporary silt fence fabric specifications for AASHTO, FHWA, and each of the comparison state DOTs. Appendix J lists the temporary silt fence fabric specifications from AASHTO, FHWA, and each of the state DOTs used for comparison with Arizona specifications.

AASHTO M288 (Table 7 – Temporary Silt Fence)

AASHTO M288 has two different strength requirements for silt fence geotextiles depending on whether the silt fence is supported by steel wire (or an equivalent polymeric mesh) or if it is unsupported. Maximum allowed post spacing is based on the elongation properties of the geotextile. Post spacing is greater for elongation less than 50 percent.

FHWA (Table 714-5 – Temporary Silt Fence)

FHWA requirements for silt fence fabric are identical to AASHTO M288 requirements. FHWA does not identify post spacing in the material specifications for silt fence fabric.

Alaska (729-2.04 – Silt Fence)

Alaska specifications follow AASHTO M288 for silt fence fabric.

California (88-1.02E – Silt Fence Fabric)

California specifications do not differentiate between requirements for supported and unsupported silt fences. California strength requirements for silt fence fabric are similar to AASHTO M288 requirements for unsupported silt fence fabric. California specifications have different permittivity requirements for woven and nonwoven silt fence fabric. California specifications also identify a water flow rate (gallons per minute per square foot) range for silt fence fabrics in accordance with ASTM D4491. Post spacing is not identified in the material specifications.

Idaho (Table 718.09-1 – Temporary Silt Fence Geotextile)

Idaho strength requirements for silt fence fabric are equivalent to AASHTO M288 requirements for supported silt fence fabric. Idaho specifications do not allow elongation greater than or equal to 50 percent on unsupported silt fences. Idaho allows a larger AOS than AASHTO M288 does. Post spacing is not identified in the material specifications.

Montana (716-06 – Temporary Silt Fence Geotextile)

Montana requirements for silt fence fabric are equivalent to AASHTO M288 requirements. Post spacing is not identified in the material specifications.

Oregon (Table 02320-3 – Geotextile for Sediment Fence)

Oregon requirements for silt fence fabric are equivalent to AASHTO M288 requirements. Post spacing is not identified in the material specifications.

Washington (9-33.2 – Table 6-Temporary Silt Fence)

Washington requirements for supported silt fence fabric are similar to AASHTO M288 requirements. Washington specifies a maximum elongation and higher strength requirements for unsupported silt fences than AASHTO M288 does. Washington also specifies a lower permittivity than AASHTO M288 does. Washington has a minimum AOS; the maximum AOS is different for slit-film woven fabric than for all other types of fabric. Post spacing is not identified in the material specifications.

Table 7 summarizes some of the key properties and trends for temporary silt fence fabric. Observations about Table 7 are discussed by property following the table.

Table 7. Silt Fence Fabric Summary/Analysis

Property	Specification	AASHTO/FHWA/State DOTs
Elongation (%)	<50, ≥50	AASHTO unsupported, FHWA Types V-B and V-C; OR unsupported; AK unsupported
	≥15, ≥50	CA
	<50	ID unsupported
	≤50 [at 267N (60lb)]	AZ
	≤30 [at ≥ 801N (180lb)]	WA unsupported
	Not Specified	AASHTO supported, FHWA Type V-A; AK supported, OR supported, WA supported, ID, MT
Grab Strength	Equivalent to AASHTO M288	AASHTO, FHWA; AK, MT, OR
	Other	CA, ID, WA, AZ
Permittivity (sec^{-1})	0.02 min.	WA
	0.05 min.	AASHTO, FHWA; AK, AZ, ID, MT, OR
	0.1 min.	CA Woven
	1.1 min.	CA Nonwoven
AOS [mm (Sieve No.)]	0.84 (20) max.	ID
	0.60 (30) max.	AASHTO, FHWA; AK, AZ, CA, MT, OR, WA (Woven Slit Film)
	0.30 (50) max.	WA (Other Types)
UV Stability (%)	70 @ 150 hours	ID
	70	AZ
	70 @ 500 hours	AASHTO, FHWA; AK, CA, MT, OR, WA

N: Newtons lb: pounds sec^{-1}: per second mm: millimeter

Observations

- **Elongation.** AASHTO, FHWA, and five states do not specify elongation requirements for supported silt fence. Arizona and two other states have maximum elongation requirements for unsupported silt fence. AASHTO, FHWA, and two states allow less than 50 percent (woven) and greater than or equal to 50 percent (nonwoven) for unsupported silt fence.
- **Grab Strength.** AASHTO, FHWA, and three states follow AASHTO M288 for strength requirements. Arizona and three other states have their own requirements for grab strength.
- **Permittivity.** Permittivity requirements vary among AASHTO, FHWA and state DOTs. Four different permittivity values are identified among the specifications in the comparison. California has different permittivity requirements for woven fabric than for nonwoven fabric.
- **AOS.** AOS requirements vary among AASHTO, FHWA, and state DOTs. Three different AOS values are identified among the specifications in the comparison. One state specifies a different AOS value for woven slit-film fabrics than for other types of fabric.

- **UV Stability.** Idaho requires 70 percent at 150 hours. AASHTO, FHWA, and five states require 70 percent at 500 hours. Arizona also requires 70 percent but does not identify the number of hours.

Recommendations

The following changes and updates are recommended for the Arizona specifications for temporary silt fence geotextile:

- **Overall.** Align the specification with AASHTO M288.
- **Elongation.** Revise elongation requirements to less than 50 percent (for woven fabric) and greater than or equal to 50 percent (for nonwoven fabric).
- **Grab Strength.** Increase the grab strength requirements for unsupported fabric to match AASHTO M288 for unsupported silt fences.
- **Post Spacing.** Allow different post spacing based on elongation and whether the fabric is supported in accordance with AASHTO M288.
- **Permittivity.** Maintain permittivity requirements defined by ADOT for local conditions since they match AASHTO M288 requirements. Permittivity is a property that agencies appear to tailor to local conditions.
- **AOS.** Maintain AOS requirements defined by ADOT for local conditions since they match AASHTO M288 requirements. AOS is a property that agencies appear to tailor to local conditions.
- **UV Stability.** Maintain UV stability requirement at 70 percent in accordance with AASHTO M288. Specify the number of hours as 500.

DRAINAGE FABRIC SPECIFICATIONS (STANDARD SPECIFICATION 1014-9)

Arizona specifications currently have a single strength of drainage fabric. The strength appears to be similar to AASHTO M288 Class 3. Arizona specifications identify one permittivity and AOS for drainage fabric but do not identify a requirement for sewn seam strength. Arizona specifications reference older test methods ASTM D4833 (for puncture strength) and ASTM D3486 (for burst strength) instead of the newer test method ASTM D6241 (for puncture strength). Arizona has a higher requirement for UV stability than AASHTO M288: 70 percent versus 50 percent at 500 hours. Arizona specifications allow only nonwoven geotextiles for drainage. The specifications call for geotextiles manufactured from fibers consisting of long-chain polymers, such as polypropylene, polyethylene, and polyester.

The following paragraphs describe the drainage fabric specifications for AASHTO, FHWA, and each of the comparison state DOTs. Appendix K lists the drainage fabric specifications for AASHTO, FHWA, and each of the state DOTs used for comparison with Arizona specifications.

AASHTO M288 (Table 2 – Subsurface Drainage)

AASHTO M288 has a single default strength of drainage geotextile, Class 2. AASHTO M288 notes that Class 3 may be specified by an engineer under certain conditions. AASHTO M288 has three sets of permittivity and AOS requirements for drainage geotextile. The applicable permittivity and AOS are based on in situ soil grain size analysis.

FHWA (Table 714-1 – Subsurface Drainage)

FHWA has two strengths of drainage geotextile. The strengths are similar to AASHTO M288 Classes 2 and 3. FHWA has higher requirements than AASHTO M288 does for puncture strength for geotextiles with elongation less than 50 percent. FHWA has three sets of permittivity and AOS requirements, which are the same as AASHTO M288**'s**. FHWA references older test methods ASTM D4833 **(**for puncture strength**)** and ASTM D3486 **(**for burst strength**)** instead of the newer test method ASTM D6241 **(**for puncture strength**)**. FHWA calls for long-chain, synthetic polymers composed at least 95 percent by mass of polyolefins or polyesters to manufacture the geotextile or the threads used to sew the geotextile.

Alaska (729.2.02 – Subsurface Drainage)

Alaska specifications follow AASHTO M288 for geotextiles for drainage.

California (88-1.02B – Filter Fabric)

California specifications have a single strength of filter fabric, which is similar to AASHTO M288 Class 2. California specifications have three sets of permittivity and opening size requirements, which are the same as AASHTO M288 requirements. California specifications have a higher requirement for UV resistance than AASHTO M288 does. The specifications reference older test method ASTM D3486 for burst strength. California does not identify a requirement or test method for puncture strength. California specifications allow only nonwoven fabric (elongation greater than or equal to 50 percent) manufactured from polyester, polypropylene, or combined polyester and polypropylene.

Idaho (718.05 Drainage Geotextile)

Idaho specifications have two strengths of drainage geotextile. Idaho specifications identify strength requirements only for grab strength and for puncture strength in accordance with ASTM D6241. No requirements for elongation or UV stability are specified. Idaho specifications identify one permittivity and AOS requirement, and call for nonwoven or monofilament woven geotextiles for drainage. Slit-film or slit-tape geotextiles are not accepted for drainage.

Montana (716.04 – Subsurface Drainage)

Montana specifications have two strengths of drainage geotextile, moderate survivability and high survivability. The strengths appear to be equivalent to AASHTO M288 Classes 1 and 2. Montana specifications have three sets of permittivity and AOS requirements, which are different from AASHTO M288 requirements. The applicable permittivity and AOS are based on in situ soil grain size analysis. Montana specifications reference older test method ASTM D4833 for puncture strength instead of the newer test method ASTM D6241. The specifications call for geotextiles manufactured from fibers consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters. Woven slit-film geotextiles are not allowed for drainage.

Oregon (Table 02320-1 – Drainage Geotextile)

Oregon specifications have two strengths of drainage geotextile. The strengths appear to be equivalent to AASHTO M288 Classes 2 and 3. Oregon specifications identify one permittivity and AOS requirement, but do not identify a requirement for sewn seam strength. Oregon specifications call for geotextiles manufactured from fibers consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters. Woven slit-film geotextiles are not allowed for drainage.

Washington (9-33.2 – Tables 1 and 2-Underground Drainage)

Washington specifications have two strengths of drainage geotextile. The strengths appear to be equivalent to AASHTO M288 Classes 2 and 3. Washington specifications have three sets of permittivity and AOS requirements, which are different from AASHTO M288 requirements but the same as Montana requirements. Washington specifications call for geotextiles manufactured from fibers or yarns consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters.

Table 8 summarizes some of the key properties and trends for drainage fabric. Observations about Table 8 are discussed by property following the table.

Table 8. Drainage Fabric Summary/Analysis

Property	Specification	AASHTO/FHWA/State DOTs
Elongation (%)	<50, ≥50	AASHTO, FHWA; AK, MT, OR, WA
	45-115	AZ
	≥50	CA
	Not Specified	ID
Geotextile Strength Classes	AASHTO Class 1 High	MT High
	Other High	-
	AASHTO Class 2 Moderate	AASHTO, FHWA Type I-A, FHWA Type I-B, FHWA Type I-C; AK Class 2, CA, MT Moderate, OR Type 2, WA Moderate
	Other Moderate	-
	AASHTO Class 3 Low	AASHTO, FHWA Type I-D, FHWA Type I-E, FHWA Type I-E; AK Class 3, OR Type 1, WA Low, ID Type II
	Other Low	AZ, ID Type I
Sewn Seam Strength	Specified	AASHTO, FHWA; AK, MT, WA
	Not Specified	AZ, CA, ID, OR
Puncture Strength	ASTM D6241	AASHTO; AK, CA, ID, OR, WA
	ASTM D4833	FHWA; AZ, MT
Burst Strength	ASTM D3786	FHWA; AZ
Permittivity (sec^{-1})	0.1 min.	AASHTO, FHWA Type I-C, FHWA Type I-F, CA Class C; AK
	0.2 min.	AASHTO, FHWA Type I-B, FHWA Type I-E, CA Class B; AK
	0.3 min.	MT Class C, WA Class C
	0.4 min.	MT Class B, WA Class B
	0.5 min.	AASHTO, FHWA Type I-A, FHWA Type I-D; AK, AZ, CA Class A, WA Class A, MT Class A, OR
	0.7 min.	ID
AOS [mm (Sieve No.)]	Not Specified	ID Type II
	0.42 (40) max.	AASHTO, FHWA Type I-A, FHWA Type I-D; CA Class A, MT Class A, OR, WA Class A
	0.25 (60) max.	AASHTO, FHWA Type I-B, FHWA Type I-E; AK, CA Class B, MT Class B,
	0.21 (70) max.	ID Type I, CA Class C
	0.18 (80) max.	MT Class C, WA Class C
	0.11-0.60 (140-30) max.	AZ
UV Stability (%)	Not Specified	ID
	50 @ 500 hours	AASHTO, FHWA; AK, MT, OR, WA
	70	AZ
	70 @ 500 hours	CA

sec^{-1}: per second   mm: millimeter

Observations

- **Elongation.** AASHTO, FHWA, and four states specify less than 50 percent and greater than or equal to 50 percent. California specifies greater than or equal to 50 percent. Arizona specifies 45 to 115 percent.
- **Geotextile Strength Classes.** The strength class determines the requirements for grab strength, sewn seam strength, puncture strength, and tear strength. Montana specifies AASHTO M288 Class 1 (high) or equivalent. AASHTO, FHWA, and five states specify AASHTO M288 Class 2 (moderate) or equivalent. AASHTO, FHWA, and four states specify AASHTO M288 Class 3 (low) or equivalent. Arizona and Idaho specify a low-strength fabric with different strength requirements than those of AASHTO M288 Class 3. AASHTO, FHWA, and the other six states have two different strength classes of fabric for drainage.
- **Sewn Seam Strength.** AASHTO, FHWA, and three states specify this property. Arizona and three other states do not specify this property.
- **Puncture Strength.** AASHTO and five states specify ASTM D6241 as the test method for measuring puncture strength. FHWA, Arizona, and Montana specify ASTM D4833 as the test method.
- **Burst Strength.** Only Arizona and FHWA specify a requirement for this property and test method.
- **Permittivity.** Permittivity requirements vary by entity. Six different permittivity values are identified among the specifications in the comparison. AASHTO, FHWA, and four states have three types or classes of fabrics, each with a different permittivity value to account for different soil gradations.
- **AOS.** AOS requirements vary by entity. Five different AOS values are identified among the specifications in the comparison. AASHTO, FHWA, and four states have more than one type or class of fabrics, each with its own AOS. Only Arizona identifies a minimum AOS.
- **UV Stability.** Idaho does not specify a requirement for UV stability. AASHTO, FHWA, and four states require 50 percent at 500 hours. One state requires 70 percent at 500 hours. Arizona also requires 70 percent but does not identify the number of hours.

Recommendations

The following changes and updates are recommended for the Arizona specifications for drainage geotextiles:

- **Fabric type.** Allow only non-woven fabric.
- **Elongation.** Revise elongation requirements to greater than or equal to 50 percent (for nonwoven fabric) to align with AASHTO M288.
- **Geotextile Strength Classes.** Align the fabric strengths with the AASHTO M288 Class 2 strength requirements.
- **Puncture Strength.** Update puncture strength requirement to refer to ASTM D6241 instead of ASTM D4833. ASTM D6241 is the test method that AASHTO M288 has adopted for puncture strength.

- **Sewn Seam Strength.** Arizona does not need to require sewn seams for drainage fabric. Typically, fabric overlaps of 12 inches are utilized according to the installation requirements in Standard Specifications Subsection 506-3.03.
- **Burst Strength.** Eliminate the burst strength requirement. AASHTO M288 does not identify requirements for this property or test method.
- **Permittivity.** Update the permittivity value to 0.5, the highest permittivity value of the three values specified by AASHTO M288. This was discussed with the TAC and selected by the committee to account for Arizona soil conditions.
- **AOS.** Update the AOS value to 0.22 mm (Sieve No. 70), the smallest AOS value of the three values specified by AASHTO M288. This was discussed with the TAC and selected by the committee to account for Arizona soil conditions.
- **UV Stability.** Specify UV stability requirement at 50 percent in accordance with AASHTO M288. Specify the number of hours as 500.

STABILIZATION FABRIC SPECIFICATIONS

Arizona does not currently have a specification for stabilization fabric. However, AASHTO and many other states do have specifications for stabilization fabric.

The following paragraphs describe the stabilization fabric specifications for AASHTO, FHWA, and each of the comparison state DOTs. Appendix L lists stabilization fabric specifications for AASHTO, FHWA, and each of the state DOTs used for comparison with ADOT specifications.

AASHTO M288 (Table 5 – Stabilization Geotextile)

AASHTO M288 has one default strength of stabilization geotextile, Class 1. AASHTO M288 notes that Class 2 or Class 3 may be specified by an engineer under certain conditions. AASHTO M288 states that stabilization geotextile is intended for "subgrade soils that are saturated due to a high groundwater table or due to prolonged periods of wet weather." Stabilization geotextile is not intended for "embankment reinforcement where stress conditions may cause global subgrade foundation or stability failure." Further, AASHTO M288 states that "reinforcement of the pavement section is a site specific design issue."

FHWA (Table 714-3 – Stabilization Geotextile)

FHWA has two strengths of stabilization geotextile. The strengths are equivalent to AASHTO M288 Classes 1 and 2. FHWA references older test methods ASTM D4833 (for puncture strength) and ASTM D3486 (for burst strength) instead of the newer test method ASTM D6241 (for puncture strength). FHWA calls for long-chain, synthetic polymers composed at least 95 percent by mass of polyolefins or polyesters to manufacture geotextile or the threads used to sew the geotextile.

Alaska (729-2.01 – Stabilization)

Alaska specifications follow AASHTO M288 for stabilization geotextile except for the permittivity. Alaska specifications require a higher minimum permittivity than AASHTO M288 does.

California (88-1.02O – Subgrade Enhancement Geotextile)

California calls its stabilization geotextile "subgrade enhancement geotextile." California specifications have two strengths of subgrade enhancement geotextile, which are similar to AASHTO M288 Classes 1 and 2. California specifications have a higher permittivity requirement and larger AOS than AASHTO M288 does for its Class B (similar to AASHTO M288 Class 1) subgrade enhancement geotextile. California specifications have a higher requirement for UV stability than AASHTO M288 does: 70 percent at 500 hours versus 50 percent at 500 hours. For Class B1 subgrade enhancement geotextile, California specifications do not identify requirements for grab strength or tear strength. Instead, requirements for wide-width tensile strength (at 5 percent strain and ultimate) are listed in accordance with ASTM D4595. A requirement for sewn seam strength is not identified. California specifications allow only geotextiles manufactured from polyester or polypropylene for subgrade enhancement.

Idaho

Idaho does not have specifications for stabilization geotextile.

Montana (716.03 – Stabilization Geotextile)

Montana specifications have a single strength of stabilization geotextile, high survivability, which appears to be equivalent to AASHTO M288 Class 1. Montana specifications have a higher permittivity requirement than AASHTO M288 does for stabilization geotextile. Montana specifications reference older test method ASTM D4833 for puncture strength instead of the newer test method ASTM D6241. Montana specifications call for geotextiles manufactured from fibers consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters. Woven slit-film geotextiles are not allowed for stabilization.

Oregon

Oregon does not have specifications for stabilization geotextile.

Washington (9-33.2 – Table 3-Geotextile for Soil Stabilization)

Washington specifications have a single strength of stabilization geotextile, which appears to be equivalent to AASHTO M288 Class 1. Washington specifications have a higher permittivity requirement than AASHTO M288 does. Washington specifications call for geotextiles manufactured from fibers or yarns consisting of long-chain polymers, composed at least 95 percent by weight of polyolefins or polyesters.

Table 9 summarizes some of the key properties and trends for stabilization fabric. Observations about Table 9 are discussed by property following the table.

Table 9. Stabilization Fabric Summary/Analysis

Property	Specification/Requirement	AASHTO/FHWA/State DOTs
Elongation (%)	<50, ≥50	AASHTO, FHWA; AK, CA, MT, WA
Geotextile Strength Classes	AASHTO Class 1 High	AASHTO, FHWA Type III-A; AK, CA Class B, WA
	AASHTO Class 2 Moderate	FHWA Type III-B; CA Class A
Sewn Seam Strength	Specified	AASHTO, FHWA; AK, MT, WA
	Not Specified	CA
Puncture Strength	ASTM D6241	AASHTO; AK, CA, WA
	ASTM D4833	FHWA; MT
Burst Strength	ASTM D3786	FHWA
Permittivity (sec^{-1})	0.05 min.	AASHTO, FHWA; CA Class A
	0.08 min.	AK
	0.10 min.	MT, WA
	0.20 min.	CA Class B
AOS [mm (Sieve No.)]	0.60 (30) max.	CA Class B1
	0.43 (40) max.	AASHTO, FHWA; AK, MT, WA
	0.30 (50) max.	CA Class B2, CA Class B3, CA Class A
UV Stability (%)	50 @ 500 hours	AASHTO, FHWA; AK, MT, WA
	70 @ 500 hours	CA

sec^{-1}: per second mm: millimeter

Observations

- **Elongation.** AASHTO, FHWA, and four states specify elongation less than 50 percent and greater than or equal to 50 percent.
- **Geotextile Strength Classes.** The strength class determines the requirements for grab strength, sewn seam strength, puncture strength, and tear strength. AASHTO, FHWA, and three states specify AASHTO M288 Class 1 (high) or equivalent. FHWA and California specify AASHTO M288 Class 2 (moderate) or equivalent.
- **Sewn Seam Strength.** AASHTO, FHWA, and three states specify this property. California does not specify this property.
- **Puncture Strength.** AASHTO and three states specify ASTM D6241 as the test method for measuring puncture strength. FHWA and Montana specify ASTM D4833 as the test method.
- **Burst Strength.** Only FHWA specifies a requirement for this property and test method.
- **Permittivity.** Permittivity requirements vary by entity. Three different permittivity values are identified among the specifications in the comparison. California has two types or classes of fabrics, each with a different permittivity value to account for different soil gradations.

- **AOS.** AOS requirements vary by entity. Three different AOS values are identified among the specifications in the comparison. California has four different classes or types, and three states have more than one type or class of fabrics, each with its own AOS.
- **UV Stability.** AASHTO, FHWA, and three states require 50 percent at 500 hours. California requires 70 percent at 500 hours.

Recommendations

The following changes and updates are recommended for the Arizona specifications for stabilization geotextiles.

- **Geotextile Strength Classes.** Add a specification equivalent to AASHTO Class 1 strength requirements.
- **Permittivity and AOS.** Identify permittivity and AOS requirements to match AASHTO M288 requirements for stabilization fabric.
- **UV Stability.** Adopt a UV stability requirement of 50 percent at 500 hours, in accordance with AASHTO M288.

GEOCOMPOSITE SPECIFICATIONS

Arizona currently has material specifications for two types or applications of geocomposites:

- Geocomposite Wall Drain System (ADOT 1014-6)
- Geocomposite Edge Drain System (ADOT 1014-7)

Both of these specifications are modified by ADOT Stored Specification 1014FAB (12/14/09).

The geocomposite drain system consists of a core material with a geotextile bonded to it. The current specifications for both of these types of geocomposite systems were reviewed and compared to specifications from other states. The review is separated into three parts: the wall drain core, the edge drain core, and the geotextile.

Not many states have specifications for geocomposites. States were selected for the comparison according to which states had specifications with enough detail to make a comparison. For wall drain systems, four states were used for the comparison: California, Kansas, Missouri, and Virginia. For edge drains, four states were used for the comparison: Missouri, Ohio, Virginia, and West Virginia.

Properties and Test Methods

The following properties and associated test methods are referenced in the discussion of edge drains and wall drains and their specifications. These properties are commonly identified when specifying requirements for edge drains, wall drains, the core material, the geotextile fabric, and the geocomposite system. ASTM D4439, *Standard Terminology for Geosynthetics*, lists definitions and descriptions for many of these properties.

Thickness with Fabric (ASTM D1777).

The thickness with fabric refers to the thickness of the edge drain or wall drain core wrapped with the geotextile fabric. Minimum thickness is expressed in units of length, inches (in). ASTM D1777, *Standard Test Method for Thickness of Textile Materials*, is the test method specified for determining the thickness with fabric.

Core Compressive Strength (ASTM D1621).

Core compressive strength refers to the compressive strength of the edge drain or wall drain core material. Core compressive strength is expressed in units of pressure, pounds per square foot (psf). ASTM D1621, *Standard Test Method for Compressive Properties of Rigid Cellular Plastics*, is the test method specified for determining core compressive strength.

Geocomposite Transmissivity (ASTM D4716).

Geocomposite transmissivity refers to the volumetric flow rate of water through the geocomposite in the direction parallel to the geocomposite. Geocomposite transmissivity is expressed in units of volume per time per unit of width, gallons per minute per foot (gal/min/ft). ASTM D4716, *Standard Test Method for Determining the (In-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using a Constant Head*, is the test method specified for determining geocomposite transmissivity.

Hydraulic Gradient.

Hydraulic gradient is a testing condition for geocomposite transmissivity. The hydraulic gradient refers to the loss of head or pressure over a distance of length.

Normal Stress.

Normal stress is a testing condition for geocomposite transmissivity. The normal stress refers to the compressive stress applied to the geocomposite in the direction perpendicular to the direction of water flow. Normal stress is expressed in units of pressure, pounds per square foot (psf).

Width.

Width refers to the width of the pavement edge drain system. The width is expressed in units of length (feet). There is no test method associated with this property.

Weight (ASTM D3776).

Weight refers to the mass per unit area for the geotextile fabric. Weight is expressed in grams per square meter (g/m^2) or ounces per square yard (oz/yd^2). ASTM D3776, *Standard Test Methods for Mass per Unit Area (Weight) of Fabric*, is the test method specified for determining geotextile weight.

Elongation (ASTM D4632).

Elongation refers to how much the geotextile stretches under tensile loading. Elongation is typically measured at the breaking or maximum load. Elongation is expressed as a percent. ASTM D4632, *Standard Test Method for Grab Breaking Load and Elongation of Geotextiles*, is the test method specified for determining elongation.

Geotextile Strength Classes.

The geotextile strength classes refer to the survivability strength classes described in AASHTO M288 where Class 1 is high strength, Class 2 is moderate strength, and Class 3 is low strength. The geotextile strength class determines requirements for grab strength, sewn seam strength, puncture strength, and tear strength.

Grab Strength (ASTM D4632).

Grab strength refers to the breaking tensile strength of the geotextile as measured in a grab test. A grab test is a tensile test where only a part of the width of the test specimen is gripped with clamps and the specimen is stretched until it breaks. The grab strength is expressed in units of force, Newtons or pounds. ASTM D4632 is the test method for determining grab strength.

Trapezoidal Tear or Tear Strength (ASTM D4533).

Trapezoidal tear or tear strength refers to the relative tear resistance of a fabric. Tear strength is measured using the trapezoid tear method. Tear strength is expressed in units of force, Newtons or pounds. ASTM D4533, *Standard Test Method for Trapezoid Tearing Strength of Geotextiles*, is the test method for determining tear strength. The trapezoid tearing strength test is useful for estimating the relative tear resistance of different fabrics or the tear resistance of different directions in the same fabric. The trapezoid tear method produces tension along a reasonably defined course such that the tear propagates across the width of the specimen.

Puncture Strength (ASTM D6241 and ASTM D4833).

Puncture strength refers to the force required for an object to puncture or penetrate a geotextile. Puncture strength is expressed in units of force, Newtons or pounds. There are two test methods identified for puncture strength; ASTM D4833 and ASTM D6241. ASTM D6241, *Standard Test Method for the Static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm*

Probe, was developed specifically for geotextiles and geotextile-related products. ASTM D4833, *Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products*, was developed for geomembranes and related products. AASHTO M288 references ASTM D6241, which is considered in the geotextile industry to be the current, accepted test method. Some entities have moved to ASTM D6241, while others, including ADOT, still specify ASTM D4833.

Burst Strength (ASTM D3786).

Burst strength refers to the pressure required to burst a geotextile using a pneumatic diaphragm bursting test. Burst strength is expressed in units of pressure, Pascals (Pa) or pounds per square inch (psi). ASTM D3786, *Standard Test Method for Bursting Strength of Textile Fabrics—Diaphragm Bursting Strength Tester Method*, is the test method for determining burst strength; however, ASTM D3786 is no longer considered to be an accepted test method in the geotextile industry. Some entities, including Arizona, still specify burst strength and refer to ASTM D3786. AASHTO M288 no longer specifies burst strength.

In Situ Soil Passing (AASHTO T88).

In situ soil passing identifies the gradation or particle size of the soil. In situ soil passing is associated with a specific opening size or sieve and is expressed in the percent of the soil (by weight) passing or going through the opening size or sieve. AASHTO T88, *Standard Method of Test for Particle Size Analysis of Soils*, is the test method for measuring soil gradation. The soil gradation is important for specifying geotextile properties such as permittivity and AOS.

Permittivity (ASTM D4491).

Permittivity refers to the volumetric flow rate of water through a cross-sectional area of geotextile in the direction normal or perpendicular to the geotextile. Permittivity is expressed in units per second (sec^{-1}). ASTM D4491, *Standard Test Methods for Water Permeability of Geotextiles by Permittivity*, is the test method for determining permittivity.

ADOT Standard Specification Section 1014 identifies Arizona Test Method 730 as the test method for measuring permittivity. ADOT Stored Specification 1014FAB (12/14/09) updates the test method for permittivity to ASTM D4491. AASHTO M288 references ASTM D4491.

AOS (ASTM D4751).

Apparent opening size (AOS) refers to the largest soil particle size that could pass through an opening in a geotextile. AOS is expressed in dimensions of opening size, millimeters (mm) or Sieve No. ASTM D4751, *Standard Test Method for Determining Apparent Opening Size of a Geotextile*, is the test method for determining AOS.

UV Stability (ASTM D4355).

Ultraviolet (UV) stability refers to the tensile strength retained by a geotextile after UV exposure for a specified amount of time. UV stability is typically measured after 500 hours of exposure. UV stability is expressed as a percent, comparing the strength after exposure to the strength of a control specimen. ASTM D4355, *Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus*, is the test method for determining UV stability.

WALL DRAIN CORE SPECIFICATIONS

The geocomposite wall drain core specification comparison is summarized in Table 10. Appendix M, Table M-1, lists the geocomposite wall drain core specifications for each of the state DOTs used for comparison with Arizona specifications.

Table 10. Wall Drain Core Summary/Analysis

Property	Specification/Requirement	States
Thickness [mm(inch)]	5.8 (0.23)	AZ
	9.7 (0.38)	MO
	Not Specified	CA, KS, VA
Compressive Strength [kPa(psf)]	276 (5,760)	VA
	278 (6,000)	MO, AZ
	479 (10,000)	CA, KS
	Not Specified	OH
Hydraulic Gradient	≤ 0.1	VA
	1.0	AZ, CA, KS
	Not Specified	MO
Normal Stress [kPa(psf)]	69 (1,440)	VA
	144 (3,000)	AZ
	239 (5,000)	CA, KS
	Not Specified	MO
Transmissivity or Flow Rate [l/min/m (gal/min/ft)]	4 (50)	AZ, CA
	5 (62)	MO
	10 (124)	KS
	15 (186)	VA

mm: millimeter kPa: kilopascal psf: pounds per square foot l: liter min: minute gal: gallon ft: foot

Observations

- **Thickness.** Thickness is related to the ability of the geocomposite to carry water through it. However, the flow rate under a hydraulic gradient and normal stress shows the amount of water that will flow through the core material under normal stress, so a thickness requirement may not be necessary on that basis. Arizona and one other state specify a thickness. Three states do not specify a thickness.

- **Compressive Strength.** The compressive strength specified should be related to the backfill pressure applied to the wall drain material, which is usually behind a retaining wall. Based on a retaining wall height of 25 feet, which is typical for a bridge abutment wall, lateral pressure on the wall drain material could be approximately 1500 psf at the bottom. However, the compressive strength required is also related to the pressure applied during the backfilling of the wall by the compaction equipment. There are three different requirements ranging from 276 kilopascals (kPa), or 5760 pounds per square foot (psf) to 479 kPa (10,000 psf). One state does not specify this property. The industry standard is 6000 psf; however, California and Kansas specify 10,000 psf.
- **Hydraulic Gradient.** This is the hydraulic gradient under which the transmissivity test is performed. A higher hydraulic gradient should result in a greater transmissivity or flow rate. Virginia specifies less than or equal to 0.1. Arizona and two other states specify 1.0. Missouri does not specify this property.
- **Normal Stress.** The normal stress is the pressure applied to the core material during the performance of the transmissivity test. A higher normal stress would tend to compress the core material resulting in a lower transmissivity or flow rate. There are three different requirements ranging from 69 kPa (1440 psf) to 239 kPa (5000 psf). Missouri does not specify this property.
- **Transmissivity or Flow Rate.** The transmissivity or flow rate is somewhat dependent on the expected magnitude of subsurface water flow into the wall drain. In Arizona, the expected flow would be low unless a spring was intercepted. There are four different requirements ranging from 50 l/min/m (4 gal/min/ft) to 186 l/min/m (15 gal/min/ft).

Recommendations

The following changes and updates are recommended for the Arizona specifications for wall drain core for geocomposites:

- **Thickness.** Eliminate the thickness requirement. It is not necessary because there is a flow rate requirement.
- **Compressive Strength.** Maintain the compressive strength requirement at 6000 psf.
- **Hydraulic Gradient.** Maintain the hydraulic gradient for the flow rate test at 1.0.
- **Normal Stress.** Raise the normal stress for the flow rate test to 5000 psf.
- **Transmissivity.** Maintain the transmissivity or flow rate requirement at 4 gal/min/ft.
- **Test Methods.** Maintain all test methods as currently specified.

EDGE DRAIN CORE SPECIFICATIONS

A summary of the geocomposite edge drain core specification comparison is shown in Table 11. Appendix M, Table M-1, lists the geocomposite core specifications for each of the state DOTs used for comparison with Arizona specifications.

Table 11. Edge Drain Core Summary/Analysis

Property	Specification/Requirement	States
Thickness [mm(inch)]	25 (1)	MO, OH
	19 (0.75)	AZ, VA, WV
Compressive Strength [kPa(psf)]	144 (3,000)	WV
	192 (4,000)	AZ
	276 (5,760)	VA
	278 (6,000)	OH
	335 (7,000)	MO
Gradient	≤ 0.1	MO, VA
	0.1	AZ, OH, WV
Normal Stress [kPa(psf)]	69 (1,440)	MO, OH, VA, WV
	72 (1,500)	AZ
Transmissivity or Flow Rate [l/min/m (gal/min/ft)]	50 (4)	AZ
	124 (10)	OH, WV
	186 (15)	MO, VA
Width [m(ft)]	0.3 (1)	AZ, MO, VA
	Not Specified	OH, WV

mm: millimeter kPa: kilopascal psf: pounds per square foot l: liter min: minute gal: gallon ft: foot

Observations

- **Thickness.** Two states specify 1 inch. Arizona and two other states specify 0.75 inch.
- **Compressive Strength.** The compressive strength specified is generally related to the pressure applied during the backfilling of the edge drain by the compaction equipment. To prevent damage to the edge drain, a high compressive strength may be specified. The industry standard now appears to be 6000 psf. Each state has a different requirement, ranging from 144 kPa (3000 psf) to 335 kPa (7000 psf).
- **Gradient.** This is the hydraulic gradient under which the transmissivity test is performed. For a highway edge drain, the water should flow easily under a low hydraulic gradient. The industry standard appears to be 0.1. Two states specify less than or equal to 0.1. Arizona and two other states specify 0.1.
- **Normal Stress.** The normal stress is the pressure applied to the core material during the performance of the transmissivity test. A higher normal stress would tend to compress the core material, resulting in a lower transmissivity or flow rate. However, for an edge drain, the pressure applied should be fairly low since the edge drain is not normally buried very deep. The industry standard appears to be 10 psi or 1440 psf. Four states specify 69 kPa (1440 psf). Arizona specifies 72 kPa (1500 psf).
- **Transmissivity or Flow Rate.** The transmissivity or flow rate is somewhat dependent on the expected magnitude of subsurface water flow into the edge drain. In Arizona, the expected flow would typically be low unless a spring was intercepted. The flow rate typically specified by

manufacturers is 15 or 21 gal/min/ft. There are three different requirements ranging from 50 l/min/m (4 gal/min/ft) to 186 l/min/m (15 gal/min/ft).

- **Width.** Two states do not specify a width. Arizona and two other states specify 0.3 m (1 ft) as the minimum width.

Recommendations

The following changes and updates are recommended for the Arizona specifications for edge drain core for geocomposites:

- **Thickness.** Maintain the thickness requirement of 0.75 inch.
- **Compressive Strength.** Raise the compressive strength requirement to 6000 psf due to pressures applied during installationonly.
- **Hydraulic Gradient.** Maintain the hydraulic gradient for the flow rate test at 0.1.
- **Normal Stress.** Change the normal stress for the flow rate test to 1440 psf.
- **Transmissivity.** Maintain the transmissivity or flow rate requirement at 4 gal/min/ft.
- **Width.** Maintain the width requirement of 1.0 foot.
- **Test Methods.** Maintain all test methods as currently specified.

EDGE DRAIN/WALL DRAIN FABRIC SPECIFICATIONS

A summary of the geocomposite fabric specification comparison is shown in Table 12. Appendix M, Table M-2, lists the geocomposite fabric specifications for each of the state DOTs used for comparison with Arizona specifications.

Table 12. Edge Drain/Wall Drain Fabric Summary/Analysis

Property	Specification/Requirement	States
Weight (oz/sq yd)	Specified	CA, KS, MO, OH, VA, WV
	Not Specified	AZ
Elongation (%)	<50, ≥50	MO, VA, WV
	≥50	CA, KS
	35-115	AZ
	Not Specified	OH
Geotextile Strength Classes	AASHTO Class 2 Moderate	CA, KS, MO,
	Other Moderate	WV
	AASHTO Class 3 Low	VA
	Other Low	AZ, OH
Puncture Strength	ASTM D6241	KS, MO, OH, WV
	ASTM D4833	AZ, OH
Burst Strength	ASTM D3786	AZ, CA
Permittivity (sec^{-1})	0.1 min.	CA Class C, KS
	0.2 min.	CA Class B, WV
	0.5 min.	AZ, CA Class A, OH, VA
	1.0 min.	MO
AOS [mm (Sieve No.)]	0.60 (30) max.	OH
	0.42 (40) max.	CA Class A, MO
	0.30 (50) max.	OH, VA
	0.25 (60) max.	CA Class B, MO, WV
	0.21 (70) max.	CA Class C, KS, MO
	0.11-0.60 (140-30)	AZ
UV Stability (%)	Not Specified	OH, VA
	50 @ 500 hours	KS
	70	AZ
	70 @ 500 hours	CA, MO, WV

oz: ounce   sq yd: square yard sec^{-1}: per second   mm: millimeter

Observations

- **Weight.** Arizona is the only state in the comparison not to specify a minimum fabric weight.
- **Elongation.** Three states specify elongation for less than 50 percent and greater than or equal to 50 percent. Two states specify greater than or equal to 50 percent. Arizona specifies 35 to 115 percent. Ohio does not specify elongation. An elongation value of greater than or equal to 50 percent results in a nonwoven fabric, which is desirable for a drainage application.
- **Geotextile Strength Classes.** The strength class determines the requirements for grab strength, sewn seam strength, puncture strength, and tear strength. Three states specify a fabric with strength requirements similar or equivalent to AASHTO Class 2 (moderate). West Virginia specifies a moderate-strength fabric with different strength requirements than those of AASHTO Class 2. Virginia specifies a fabric with strength requirements similar or equivalent to AASHTO

Class 3 (low). Arizona and Ohio specify a low-strength fabric with different strength requirements than those of AASHTO Class 3.

- **Puncture Strength.** Four states specify puncture strength according to ASTM D6241. Arizona and Ohio specify puncture strength according to ASTM D4833.
- **Burst Strength.** Arizona and California specify burst strength according to ASTM D3786.
- **Permittivity.** Permittivity requirements vary by state. There are four different permittivity values specified by the states in the comparison. California has three different fabric classes, each with different permittivity values.
- **AOS.** There are six different AOS requirements specified by the different states. Arizona is the only state to identify a minimum AOS. California has three different fabric classes, each with different AOS values. Two states have an AOS that depends on the gradation of the soil.
- **UV Stability.** Two states do not specify UV stability. Kansas specifies 50 percent at 500 hours. Three states specify 70 percent at 500 hours. Arizona specifies 70 percent but does not identify the number of hours.

Recommendations

The following changes and updates are recommended for the Arizona specifications for fabric for geocomposites:

- Use the specification for Drainage Fabric (ADOT 1014-9).

GEOGRID SPECIFICATIONS

The material requirements for geogrid are identified in ADOT Standard Specification Section 1014-3. The installation and application specifications for geogrid are contained in ADOT Standard Specification Section 306.

Standard Specification Section 1014-3 calls for a biaxial polymer grid designed for use as base reinforcement. Standard Specification Section 1014-3 allows polypropylene or high-density polyethylene materials. The grid manufacture type can be punched and drawn or extruded. The test methods and associated material properties identified in Standard Specification Section 1014-3 for geogrid are shown in Table 13.

Table 13. Arizona Requirements for Geogrids[(1), (2)]

Property	Requirement	Test Method
Average Aperture Size (in) MD [(4)] XD [(5)]	 0.8 - 2.0 0.8 - 2.0	I .D. Calipered, [(3)]
Open Area: (%)	70 min., [(6)]	USACE Method, [(7)]
Weight: (oz. / yd.)	5.5 min.	ASTM D3776
Thickness: (mils) At Rib At Junction	 30 min. 60 min.	ASTM D1777
Wide-Width Strip Tensile Strength (lb. / ft.): At 2% Strain At 5% Strain At 15% Strain or Ultimate	 275 min. 550 min. 800 min.	ASTM D4595
Flexural Rigidity: (mg-cm)	250,000 min.	ASTM D1388
Junction Strength: (%)	80 min.	ASTM D638 Mod[(8)]

(1) ADOT Standard Specification Section 1014-3
(2) Definition of Units: min-minute; oz-ounce; yd-yard; lb-pound; ft-foot; mg-milligram
(3) Maximum inside dimension in each principal direct ion measured by calipers.
(4) MD-Machine direct ion which is along roll length.
(5) XD-Cross machine direction which is across the roll width.
(6) Minimum - Average value in weaker principal direction. All numerical values represent minimum average roll values, i.e., the average test result in the weaker principal direct ion shall meet or exceed minimum values listed when sampled according to ASTM D 4354 and tested according to the test method specified above.
(7) Percent open area measured without magnification by the USACE Method as specified in CW 02215, Civil Works Construct ion Guide, November 1977.
(8) Junction strength is measured as a percent of ultimate single rib strength by tensile loading test ASTM D 638 modified to clamp the horizontal and vertical ribs of a "T" shaped specimen, with the grid junction forming the cross of the "T", and with a constant rate of extension of the specimen applied across the junction at a rate of two inches per minute at a temperature of 68 degrees F.

The current Arizona specifications for geogrid were compared to geogrid specifications from other states. Ten states were selected for the comparison: Alaska, California, Indiana, Kansas, Kentucky, Maine, New Mexico, Ohio, Oklahoma, and Utah. AASHTO M288 does not provide recommended test methods or specifications for geogrids.

Types of Geogrid

Arizona currently specifies only one type of biaxial geogrid. Since the Arizona specification was developed, the number of types of geogrid on the market has expanded. In addition to different strengths of biaxial geogrid, triaxial geogrid is now available on the market. Many states have developed more than one geogrid specification to address the different types of geogrid available on the market. Of the 10 states compared, New Mexico covers the most types of geogrid in its specification. The New Mexico specification has two types and strengths of biaxial geogrid, as well as two types and strengths of triaxial geogrid. Utah also has two types and strengths of geogrid for subgrade stabilization, and two types and strengths of geogrid for base reduction. Indiana, Kansas, Kentucky, and Oklahoma each specify two types of geogrid. Table 14 summarizes the number of geogrids used by Arizona and the 10 states in the comparison.

Table 14. Geogrid Types Specified

No. of Geogrid Types Specified	Applicable States
1	AZ, AK, CA, ME, OH
2	IN, KS, KY, OK
3	None
4	NM, UT

Specifications and design guidelines for geogrid are addressed in detail in Chapters 4 and 5. However, it is worthwhile to mention at this point that Arizona should consider expanding the specifications for geogrid to include more than one strength of biaxial geogrid and to allow for triaxial geogrid.

Properties and Test Methods

The following properties and associated test methods are referenced in the discussion of geogrids and their specifications. These properties are commonly identified when specifying requirements for geogrid products. ASTM D4439, *Standard Terminology for Geosynthetics*, lists definitions and descriptions for many of these properties.

Average Aperture/Opening Size (Direct Measure with Caliper)

The average aperture/opening size refers to the size of the opening between the ribs for the geogrid. The average aperture/opening size is expressed in inches and is measured directly with a caliper. An acceptable opening size is related to the size of aggregate in the base course. The minimum opening size should be $\geq D_{50}$ of the aggregate above the geogrid to provide interlock, but not less than ½ inch (12.5 mm), where D_X is the size of sieve through which x percent of the total material would pass. The maximum opening size should be $\leq D_{85}$ to prevent aggregate from penetrating through the geogrid into the subgrade.

Open Area (CW 02215)

Open area refers to the overall percent of the geogrid that is an opening. Open area is expressed as the percent of the total area of the geogrid. This test method is from the Corps of Engineers *Civil Works Construction Guide–Specification for Plastic Filter Fabrics* CW-02215 (USACE 1977) and is for measuring the percent of a fabric that is open. Geogrids inherently have openings to provide the aggregate interlock. Between the openings, there are ribs in either two (biaxial) or three (triaxial) directions. For a biaxial geogrid, the openings are rectangular; for triaxial geogrids, the openings are triangular. The opening size and percent open area define the size and number of the openings.

Weight (ASTM D3766)

Weight refers to the weight per unit area of the geogrid material. Weight is expressed in units of ounces per square yard. ASTM D3766, *Standard Test Methods for Mass per Unit Area (Weight) of Fabric*, is for the measurement of fabric mass per unit area (weight) and is applicable to most fabrics. The weight is dependent upon the amount of plastic material utilized in the manufacture of the geogrid and the way it was extruded and stretched. A higher weight may or may not be related to the strength of the geogrid. Typically, a higher weight for a geogrid type indicates a higher geogrid strength, but not always. Most current specifications do not specify weight, since weight does not directly correlate to the performance of the geogrid.

Thickness (ASTM D1777)

Thickness refers to the thickness of ribs or junctions of the geogrid. Thickness is expressed in units of mils (.001 inch). ASTM D1777, *Standard Test Method for Thickness of Textile Materials*, is the test method for determining the thickness of a textile fabric material. The thickness of the geogrid ribs or junctions is somewhat dependent upon the amount of plastic material utilized in the manufacture of the geogrid and the way it was extruded and stretched. A higher rib or junction thickness may be related to the geogrid strength for a certain manufacturing process, but a different manufacturing process may result in a significantly different strength for the same rib or junction thickness. As a result, the rib or junction thickness may not be related to the strength of the geogrid. Most current specifications do not specify the rib or junction thicknesses, since they do not directly correlate to the performance of the geogrid.

Wide-Width Strip Tensile Strength ASTM D4595)

Wide-width strip tensile strength refers to the measured tensile strength of a strip of geogrid at low levels of strain and sometimes at ultimate failure. The wide-width strip tensile strength is expressed in units of pounds per foot (lb/ft). ASTM D4595, *Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method*, is the test method for determining the wide-width strip tensile strength of a geogrid or geotextile fabric. The wide-width strip tensile test provides an assessment of the overall geogrid tensile strength. ASTM D4595 requires the entire width of the sample to be clamped. The clamps are 8 inches by 2 inches. The geogrid sample is 8 inches wide by 8 inches long (minimum). Since the entire width of the sample is held by the clamps, this is a true tensile test. The “pounds of force" is then divided by 8, multiplied by 12, and reported as pounds per foot. To verify the strength of the geogrid at low strain levels, which are important in base reinforcement or stabilization applications, the wide-width strength tensile strength is commonly measured at low strain levels such as 2 percent or 5 percent.

Tensile Strength (ASTM D6637)

Tensile strength refers to the measurement of the geogrid tensile strength utilizing a single rib or several ribs at low levels of strain and sometimes at ultimate failure. The tensile strength for geogrids is expressed in units of pounds per foot (lb/ft). ASTM D6637, *Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method*, is the test method for determining the tensile strength of geogrids. Method A of the test is for a single rib, and Method B is for multiple ribs. The multiple rib test is similar to the wide-width strip tensile strength test. For Method A, the single rib test, the "pounds of force" is multiplied by the number or ribs per foot for the geogrid and reported as pounds per foot. For Method B, the multiple rib test, the "pounds of force" is divided by the number of ribs tested and multiplied by the number or ribs per foot for the geogrid and reported as pounds per foot. The ends of the geogrid sample, whether single or multiple ribs, are held by clamps, so this is a true tensile test. To verify the strength of the geogrid at low strain levels, which are important in base reinforcement of subgrade stabilization applications, the tensile strength is commonly measured at low strain levels such as 2 percent or 5 percent.

Tensile Modulus (ASTM D6637)

Tensile modulus refers to the tensile strength gain per unit of strain measured at a certain strength level on the tensile strength/strain curve. Tensile modulus is expressed in units of pounds per foot (lb/ft). ASTM D6637, *Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method*, is the test method for determining the tensile modulus of geogrids. Method A of the test is for a single rib, and Method B is for multiple ribs. For Methods A or B, the "pounds of force" at a certain strain level is divided by the actual strain converted to feet of movement and reported in pounds per foot. The secant tensile modulus is sometimes specified, which is the slope of the stress-strain curve at a specified strain level, such as 2 percent or 5 percent. The ends of the geogrid sample, whether single or multiple ribs, are held by clamps, so this is a true tensile test. The tensile modulus is commonly measured at low strain levels such as 2 percent or 5 percent. For base reinforcement and especially for subgrade soil stabilization, the parameter used to define the effectiveness of a geogrid product is the tensile modulus at low strains, usually at 2 percent strain, or sometimes even at smaller strains.

Flexural Rigidity (ASTM D1388) or Flexural Stiffness (ASTM D7748)

Flexural rigidity or flexural stiffness refers to the stiffness of the geogrid. Flexural rigidity or flexural stiffness is measured in milligrams per centimeter (mg-cm). ASTM D 1388, *Standard Test Method for Stiffness of Fabrics,* or the newer ASTM D7748, *Standard Test Method for Flexural Rigidity of Geogrids, Geotextiles and Related Products*, are the test methods for determining the flexural rigidity or stiffness of geogrids. Since ASTM D7748 is specifically for geogrids, it appears to be the test method that should be utilized if this property is specified. The property of high flexural stiffness is used to distinguish extruded and drawn geogrid from woven fabric geogrid. Specifying that the geogrid must be extruded would also serve this purpose. Most geogrid manufacturers for extruded geogrids specify some degree of flexural stiffness. In addition, the flexural stiffness is typically higher for geogrids with a higher tensile strength.

Junction Strength/Junction Efficiency (ASTM D7737)

Junction strength/junction efficiency refers to the tensile strength at the geogrid junctions either in pounds per foot or as a percentage of the overall geogrid tensile strength. ASTM D7737, *Standard Test Method for Individual Geogrid Junction Strength*, is the test method for determining the junction strength or junction efficiency. The use of junction strength or junction efficiency is another way of ensuring that extruded geogrids are utilized for base reinforcement or subgrade stabilization, since extruded geogrids have a high junction strength and woven fabric geogrids do not. In theory, the geogrid junctions must be strong to maintain the opening size in the geogrid that allows for the interlocking of the aggregate within it. The junction strength is typically specified as being a percentage of the geogrid tensile strength, such as 90 percent (or the tensile strength in pounds per foot that is equal to 90 percent).

Torsional Rigidity or Aperture Stability at 20 kg-cm (USACE/GRI GG9)

Torsional rigidity or aperture stability refers to the measurement of the resistance to in-plane rotational movement measured by applying a 20 kg-cm (2 m-N) moment to the central junction of a 9 inch by 9 inch specimen restrained at its perimeter in accordance with USACE Methodology or Geosynthetic Research Institute Test Method GG9, *Torsional Behavior of Bidirectional Geogrids When Subjected to In-Plane Rotation*. In this test method, an unsupported square geogrid specimen is fixed on its four sides in a horizontally oriented containment box. Its central node is then clamped by a torqueing device, which has the capability of applying moment to the geogrid structure and simultaneously measuring the resulting rotation. The modulus of the rotation-versus-moment curve is the desired value of geogrid stiffness in units of newton-meter/degree (N-M/degree) or millimeter-kilogram per degree (mm-kg/degree). The assumption is that geogrids with high torsional rigidity perform better than geogrids with less torsional rigidity, such as woven geogrids, because they are more effective at maintaining the interlock and lateral restraint of the granular base course material.

Installation Damage Resistance (ASTM D5818)

Installation damage resistance refers to the comparison of a geogrid's original tensile strength to its tensile strength after installation and removal. The installation damage resistance is expressed in percent of the original tensile strength. ASTM D5818, *Standard Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics*, is the test method for retrieving geotextile samples for testing after installation. ASTM D6637, *Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method*, is the test method for determining the tensile strength of geogrids before and after installation. This process would likely require a test section for evaluation.

UV Stability (ASTM D4355)

UV stability refers to the comparison of a geogrid's original tensile strength to its tensile strength after exposure to a specified duration of UV radiation. The UV stability is expressed in percent of the original tensile strength. ASTM D4355, *Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus*, is the test method for producing deterioration of the geogrid due to UV radiation. ASTM D6637, *Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method*, is the test method for comparing the tensile strength of geogrids before and after UV deterioration. The length of exposure to UV radiation is typically 500 hours, and the UV stability required is usually 70 percent.

Coefficient of Soil Interaction (ASTM D6706)

The coefficient of soil interaction is essentially the ratio between the pullout resistance and the normal load for a geogrid pullout test in soil. ASTM 6706, *Standard Test Method for Measuring Geosynthetic Pullout Resistance in Soil*, is the test method utilized for determining the coefficient of soil interaction. This property is typically determined from large-scale pullout tests, where the geogrid is sandwiched within the soil or aggregate, a normal load is applied to the soil or aggregate surrounding the geogrid, and the geogrid is pulled horizontally out of the soil. The ratio of the pullout load resistance to the normal load defines the coefficient of soil interaction. The results of this test depend heavily on the type of soil or aggregate and the magnitude of the normal load applied. This property is more relevant to slope reinforcement or MSE wall applications, for which normal loads are high due to the depth of embedment, than to a pavement section application, for which the normal load would be very low in comparison. As a result, this property would not normally be specified for a geogrid utilized for base reinforcement or subgrade stabilization.

Appendix N presents tables comparing ADOT geogrid specifications with specifications from 10 other states. Table 15 summarizes the geogrid specification comparison.

Table 15. Geogrid Specifications Summary/Analysis

Property	Summary of Specifications
Average Aperture Size (in) MD (machine direction) XD (cross machine direction)	1 state specifies the same range as ADOT; 2 states specify a minimum between ADOT's range; 4 states specify a narrower range than ADOT; and 2 states specify a wider range than ADOT
Open Area (%) USACE Method	1 state specifies the same number as ADOT; 2 states specify a range which includes ADOT's minimum
Weight (oz/yd) ASTM D3776	ADOT is the only state in this group that specifies weight
Thickness (mils) ASTM D1777 At Rib At Junction	3 states specify thickness with requirements slightly different than ADOT
Wide-Width Strip Tensile Strength (lb/ft) ASTM D4595 At 2% Strain At 5% Strain At 15% Strain or ultimate	2 states specify higher values than ADOT, but no value for 15%/ultimate strength
Tensile Strength (lb/ft) ASTM D6637 At 2% Strain At 5% Strain At ultimate	ADOT does not have this specification; 3 states specify 2% & 5% values; 3 states specify 2% & ultimate values; 3 states specify an ultimate value only
Tensile modulus (lb/ft) MD XD	ADOT does not have this specification; 4 states specify values for this property
Flexural Rigidity (mg-cm) ASTM D1388	ADOT does not have this specification; 1 state specifies values for two types of geogrids
Overall flexural rigidity (mg-cm)	ADOT does not have this specification; 2 states specify values
Junction Strength (%)-ASTM D638	ADOT does not have this specification; no states have specifications for this property
Junction Strength (%), (lb), (lb/ft)-GRI[(1)] GG2	5 states specify values
Junction Efficiency (%) ASTM D7737	ADOT does not have this specification; 1 state specifies a value
Junction Strength (lb/ft) ASTM D7737	ADOT does not have this specification; 4 states specify values
Torsional Rigidity at 20 cm-kg (mm-kg/degree) GRI-GG9	ADOT does not have this specification; 3 states specify values
Installation Damage Resistance (%) ASTM D6637	ADOT does not have this specification; 1 state specifies a value
Resistance to long-term degradation (%) EPA 9030 and ASTM D4355	ADOT does not have this specification; 2 states specify values
Ultraviolet Resistance, % retained tensile strength, 500 hours ASTM D4355	ADOT does not have this specification; 3 states specify values
Coefficient of Soil Interaction	ADOT does not have this specification; 1 state specifies a value

in: inch oz: ounce yd: yard lb: pound ft: foot

mg: milligram cm: centimeter kg: kilogram mm: millimeter

(1) GRI denotes Geosynthetic Research Institute.

Observations

Arizona's geogrid specifications include requirements for average aperture size, open area, weight, thickness, wide-width strip tensile strength, and junction strength (using test method GRI GG2).

Arizona's standards for these properties appear to be in line with the other state standards evaluated. Arizona is the only state in the comparison that specified weight as a geogrid property.

There are several properties and test methods that are identified by various states in their geogrid specifications. The least used properties, with the number of states using it, are:

- Flexural Rigidity (mg-cm) ASTM D1388 — one state.
- Overall Flexural Rigidity (mg-cm) ASTM D7748— two states.
- Junction Strength (%)-ASTM D638 — only ADOT.
- Junction Efficiency (%) ASTM D7737 — one state.
- Installation Damage Resistance (%) ASTM D6377 — one state.
- Resistance to Long Term Degradation (%) EPA 9030 and ASTM D4355 — two states.
- Coefficient of Soil Interaction GRI-GT6/GG5 — one state.

Recommendations

The following changes and updates are recommended for the Arizona specifications for fabric for geogrid:

- **Geogrid Type.** Revise the specifications to allow the stronger type of biaxial geogrid (Type 2) and provide an alternative specification for triaxial geogrid. The triaxial geogrid is currently a sole source product.
- **Aperture Size.** Revise the average aperture size to 0.8 to 1.4 inches. An opening of 2.0 inches is too large for Arizona's aggregate base course (ABC).
- **Test Methods.** Change the test method for tensile strength (lb/ft) to ASTM D6637.
- **Tensile Strength.** Specify tensile strength requirements for Type 2 biaxial geogrid.
- **Junction Efficiency.** Specify junction efficiency (percent) requirements measured in accordance with ASTM D7737 at 93 percent for Type 2 biaxial geogrid.
- **UV Stability.** Specify UV Stability, percent retained tensile strength, at 100 percent after 500 hours, in accordance with ASTM D4355.

The strength requirements for geogrids should be based on the design guidelines for ADOT pavement design utilizing geogrids for subgrade stabilization or base reduction. This should be called out in the project special provisions as specified in the ADOT *Materials Design Memorandum* on a project-by-project basis.

GEOMEMBRANE SPECIFICATIONS

Arizona has a stored specification 208GEOM, dated December 2, 1991, Item 2080031 – *Geomembrane*, which has been used rarely on roadway projects to isolate or encapsulate expansive subgrade soils. Soil heave in expansive clay soils is caused by increased moisture in the soils. A geomembrane is placed on the expansive clay subgrade to isolate it. The geomembrane prevents moisture that infiltrates through cracks in the asphalt roadway above from reaching the subgrade soils. This is particularly important when an aggregate base course immediately underlies the asphalt.

The benefit of maintaining a geomembrane specification is that it can be used for a separation and reinforcing function as well as for preventing moisture intrusion into the roadway subgrade. There may be a cost savings to using a fabric-reinforced geomembrane rather than conventional geotextile fabrics where expansive or collapsible subgrade soils are encountered.

Properties and Test Methods

The following properties and associated test methods are referenced in the discussion of geomembranes and their specifications. These properties are commonly identified when specifying requirements for geomembrane products.

Fabric Weight

Weight refers to the weight per unit area of the geomembrane material. Weight is expressed in units of ounces per square yard. There is no test method associated with this property.

Width

Width refers to the width of the geomembrane material. The width is expressed in units of length (ft). There is no test method associated with this property.

Thickness (ASTM D1777)

Thickness is expressed in units of length (inches). ASTM D1777, *Standard Test Method for Thickness of Textile Materials*, is the test method specified for determining thickness.

Grab Tensile Strength (ASTM D4632)

Grab strength refers to the breaking tensile strength of the geomembrane as measured in a grab test. A grab test is a tensile test where only a part of the width of the test specimen is gripped with clamps, and the specimen is stretched until it breaks. The grab strength is expressed in units of force (Newtons or pounds). ASTM D4632 is the test method for determining grab strength.

Grab Elongation at Break (ASTM D4632)

Grab elongation refers to how much the geomembrane stretches under tensile loading. Elongation is typically measured at the breaking or maximum load. Elongation is expressed as a percent. ASTM D4632, *Standard Test Method for Grab Breaking Load and Elongation of Geotextiles*, is the test method specified for determining elongation.

Puncture Strength (ASTM D4833)

Puncture strength refers to the force required for an object to puncture or penetrate a geotextile. Puncture strength is expressed in units of force (Newtons or pounds). There are two test methods identified for puncture strength: ASTM D4833 and ASTM D6241. ASTM D6241, *Standard Test Method for the Static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm Probe*, was developed specifically for geotextiles and geotextile-related products. ASTM D4833, *Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products*, was developed for geomembranes and related products. AASHTO M288 references ASTM D6241, which is considered in the geotextile industry to be the current, accepted test method. Some entities have moved to ASTM D6241, while others, including ADOT, still specify ASTM D4833.

Burst Strength (ASTM D3786)

Burst strength refers to the pressure required to burst a geomembrane using a pneumatic diaphragm bursting test. Burst strength is expressed in units of pressure (Pascals or pounds per square inch). ASTM D3786, *Standard Test Method for Bursting Strength of Textile Fabrics—Diaphragm Bursting Strength Tester Method*, is the test method for determining burst strength. ASTM D3786 is no longer considered to be an accepted test method in the geotextile industry. Some entities, including Arizona, still specify burst strength per ASTM D3786. AASHTO M288 no longer specifies burst strength.

Trapezoidal Tear or Tear Strength (ASTM D4533)

Trapezoidal tear or tear strength refers to the relative tear resistance of a fabric. Tear strength is measured using the trapezoid tear method. Tear strength is expressed in units of force (Newtons or pounds). ASTM D4533, *Standard Test Method for Trapezoid Tearing Strength of Geotextiles*, is the test method for determining tear strength. The trapezoid tearing strength test is useful for estimating the relative tear resistance of different fabrics or the tear resistance of different directions in the same fabric. The trapezoid tear method is a test that produces tension along a reasonably defined course such that the tear propagates across the width of the specimen.

Permittivity (ASTM D4491)

Permittivity refers to the volume flow rate of water through a cross-sectional area of geomembrane in the direction normal or perpendicular to the geomembrane. Permittivity is expressed in units per second. ASTM D4491, *Standard Test Methods for Water Permeability of Geotextiles by Permittivity*, is the test method for determining permittivity.

ADOT Standard Specification Section 1014 identifies Arizona Test Method 730 as the test method for measuring permittivity. ADOT Stored Specification 1014FAB (12/14/09) updates the test method for permittivity to ASTM D4491. AASHTO M288 references ASTM D4491.

Water Permeability

Water permeability refers to the rate, in volume of water per surface area, at which water passes through the geomembrane.

Abrasion Resistance

Abrasion resistance refers to the ability of the geomembrane material to resist scuffing, scratching or rubbing away of the surface exposed material.

UV Stability

UV stability refers to the tensile strength retained by a geomembrane after UV exposure for a specified amount of time.

Geomembrane Specifications

The following paragraphs describe the geomembrane specifications of four state DOTs that were used for comparison: Colorado, Kansas, South Dakota, and Texas.

Colorado (712.01 (a) – Geomembrane)

The Colorado geomembrane specification is presented in Subsection 712.01 (a) *Geomembrane*. This specification, for a polyvinyl chloride (PVC) geomembrane manufactured for stopping seepage loss, gives material requirements for three thicknesses: 10 mil, 20 mil, and 30 mil. In Subsection 420.05, *Impervious Lining*, the construction requirements are provided. According to the specification, the geomembrane is not used for soil encapsulation below a pavement section on a roadway.

Kansas (Special Provision 07-08043 – Geomembrane)

Kansas specifications have a special provision for geomembrane, also called an impermeable moisture barrier: Stored Specification 07-08043, *Geomembrane*. It is for a 30 mil thick geomembrane, and it is utilized for roadway applications. The geomembrane may be polypropylene or polyethylene, and there are different requirements for each. The specification requires cushioning sand over the geomembrane.

South Dakota (831 – Geotextile and Impermeable Plastic Membrane)

Section 831, South Dakota's geotextile specification, lists requirements for impermeable plastic membrane in a table along with the requirements for conventional geotextile fabrics. The table lists a thickness requirement and various strength requirements. No construction or installation requirements are given. The table does include a note, which states: "Under Pavements. Used to restrict the flow of fluids to underlying materials."

Texas (DMS 6210 – Vertical Moisture Barrier)

Texas DMS 6210 is a specification for a vertical moisture barrier. These vertical barriers have been installed along existing pavement sections to a depth of 8 feet to encapsulate the pavement subgrade and maintain the moisture content of the expansive soils below the roadways. The specification lists a fabric weight but no thickness requirement; it also provides required values for tensile strength, apparent elongation at break, and tear strength.

Table 16 summarizes some of the key properties for geomembrane. Colorado was not included in the comparison because geomembrane is not utilized in Colorado roadway applications. Observations about Table 16 are discussed by property following the table.

Table 16. Geomembrane Summary/Analysis (English Units)

Property	**ADOT Specification**	**State DOTs**
Fabric Weight (oz./yd^2)	Not specified	Kansas – Not specified South Dakota – Not specified Texas – 6.5 min. (TEX-616-J)
Width (ft.)	9 min. (No Test Method)	Not specified by any other state
Thickness (mils)	14 min. (ASTM D1777)	Kansas – 30 min. South Dakota – 12 min. Texas – 20 min.
Grab Tensile Strength (lb)	170 min. (ASTM D4632)	Kansas – 78 lb/in. min. (ASTM D638) South Dakota – 80 lb/in. min. (ASTM D4595) Texas – 150 min. (ASTM D5034)
Grab Elongation at Break (%)	20 min. (ASTM D4632)	Kansas – Not specified South Dakota – 20 min. (ASTM D4595) Texas – 20 min. (ASTM D5034)
Puncture Strength (lb)	70 min. (ASTM D4833)	Kansas – 40 to 45 min. South Dakota – 60 min. Texas – Not specified
Burst Strength (psi)	250 min. (ASTM D3786)	Not specified by any other state
Trapezoidal Tear (lb) or Tear Strength	40 min. (ASTM D4533)	Kansas – 24 min. (ASTM D1004) South Dakota – 50 min. Texas – 15 min. (ASTM D751)
Permittivity (sec^{-1})	0 max. (ASTM D4491)	Not specified by any other state South Dakota has a maximum permeability requirement of <0.0000010 cm/sec
Water Permeability (oz./yd^2)	Not specified	Texas - 0.6 max. (TEX-616-J)
Abrasion Resistance (oz./yd^2)	Not specified	Texas – 0.6 max. (TEX-616-J)
UV Stability (%)	Not specified	Not specified by any state

oz: ounce yd: yard lb: pounds psi: pounds per square inch sec^{-1}: per second

Observations

- **Fabric Weight.** Fabric weight is only specified by Texas and does not appear critical to geomembrane performance.
- **Width.** Roll width is only specified by Arizona. Roll width is only important to the contractor since it is an installation issue. A geomembrane overlap of 24 inches is required during installation, so roll width has an impact on the overall square yards of geomembrane placed. If the roll width is 9 feet, 2 feet of the roll width will be lost in the overlap on each side—4 feet total. The higher the roll width, the less material loss. Roll width is not critical to the geomembrane performance.
- **Thickness.** The geomembrane thickness is somewhat related to the strength and durability of the geomembrane. All states with a geomembrane specification have a thickness requirement.
- **Grab Tensile Strength, Wide-Width Tensile Strength or Tensile Strength (1-inch Strip).** Only the grab tensile strength at break or yield is specified by all states. Arizona has the highest grab tensile strength requirement, but it is comparable to Texas. Since the geomembrane application in a pavement structure requires strength, Arizona's grab tensile strength requirement appears most appropriate. However, a review of industry specifications indicates that the tensile strength normally specified for composite geomembranes is in lb/ft as determined by the 1-inch strip test according to ASTM D882. Breaking elongation (%) is also part of the test result for each of the different tensile tests.
- **Puncture Strength.** All of the states that specify a puncture strength requirement utilize ASTM D4833 for the test method. Arizona has the highest puncture strength requirement, but it is only slightly higher than South Dakota's requirement in a similar application. Since the geomembrane application in a pavement structure requires strength during installation, Arizona's puncture strength requirement appears most appropriate. Since the geomembrane may be used for stabilization and separation as well as for an impermeable moisture barrier in the pavement structure, the puncture strength requirement should be similar to the requirement for a stabilization or separation fabric, and perhaps should be tested in accordance with ASTM D6241, the new test method for puncture strength.
- **Burst Strength.** Only Arizona specifies a burst strength requirement for geomembrane. Since the new ASTM D6241 puncture test is similar to the old burst strength test, the burst strength is no longer normally specified.
- **Trapezoidal Tear or Tear Strength.** All the states specify some form of tear strength test, although the trapezoidal tear test is mostly specified for geotextiles. If the tensile and puncture strengths meet the specifications, a high tear strength will also result. Arizona's tear strength requirement is similar to South Dakota's, only slightly lower. If geomembranes will be utilized for a separation/stabilization function as well as for an impermeable moisture barrier, then a higher tear strength would be required, as it would for a geotextile in the same application.
- **Permittivity.** Because geomembranes are supposed to be impermeable, a permittivity of 0 should be expected (although even a geomembrane has some permittivity). It is unlikely that such a low permittivity would be measurable using ASTM D4491. Therefore, the permittivity requirement should be deleted.

- **UV Stability.** UV stability is not specified by any state, but it probably should be if the geomembrane is to have a dual purpose as an impermeable moisture barrier and in a separation/stabilization function.

Recommendations

The following changes and updates are recommended for the Arizona stored specification for geomembrane:

- **Specification Title.** Rename the specification *Composite Geomembrane* to more accurately describe the composite of a fabric and geomembrane that should meet the strength, puncture, burst, and tear requirements.
- **Specification Type.** Incorporate the specification into the Standard Specifications.
- **Moisture Barrier.** Delete the moisture barrier option at Section 2080031(2)(a), *Impervious Sheet,* because an impervious sheet (or film geomembrane) of single-layer construction will not conform to the listed strength requirements. Instead, use Section 2080031(2)(b), *Fabric Reinforced Geomembrane, of Composite Construction*.
- **Roll Width.** Remove the requirement for roll width.
- **Thickness.** Remove the requirement for thickness, since thickness will be defined by the strength and durability requirements.
- **Tensile Strength.** The tensile strength required should be equivalent to a 1-inch strip tensile strength result in lb/ft that is approximately three times the tensile strength for a normal grab tensile strength test, which is for a 4-inch wide specimen based on the requirements for a Class 1 or 2 geotextile, or whatever test is available according to industry specifications for a composite geomembrane.
- **Puncture Strength.** Change the puncture strength requirement to match AASHTO M288 for Class 1 or 2 geotextile.
- **Burst Strength.** Remove the burst strength requirement.
- **Trapezoidal Tear.** Change the trapezoidal tear requirement to match AASHTO M288 for Class 1 or 2 geotextile.
- **Permittivity.** Remove the permittivity requirement; just specify that the geomembrane must be impermeable.
- **UV Stability.** Specify a UV stability requirement equivalent to that of AASHTO M288 for Class 1 or 2 geotextile.

SUMMARY OF FINDINGS

This chapter presents a comprehensive review of geosynthetic specifications applicable to road and highway construction. Based on information from other states and federal agencies, recommendations related to revising and updating ADOT's Standard Specifications for geosynthetic products were identified.

USING INFORMATION IN THIS CHAPTER

The recommendations presented in this chapter were used along with design guidelines and life-cycle cost analysis to prepare revised specifications for geosynthetic materials. ADOT should consider these recommendations, along with their current policies regarding road construction, to identify which recommendations to apply.

CHAPTER 4: DESIGN GUIDELINES FOR BASE/SUBBASE REINFORCEMENT

INTRODUCTION

The objective of Chapter 4 is to present updated design guidelines for geosynthetics used for base or subbase reinforcement. Base or subbase reinforcement refers to the use of lateral confinement to improve the load-carrying capacity of the pavement system under repetitive traffic loadings. The reinforcement function is typically accomplished by using geogrids. However, geotextiles are also used for separation in transportation applications.

The design guidelines were developed through two tasks. The first was to review existing ADOT design guidelines and compare them to other available industry design guidelines. The second was to review performance-related studies for geosynthetics to investigate the practical application of the design theories and methodologies.

BASE AND SUBBASE REINFORCEMENT OVERVIEW

Two of the potential design benefits of using geosynthetics for base/subbase reinforcement in pavement design are the ability to reduce the pavement section thickness—ABC and/or asphaltic concrete (AC)—and to extend the life of the pavement. Reducing the pavement section thickness in the design pavement section may result in a cost savings.

The ABC thickness reduction is assessed by using a base course reduction (BCR) factor. The BCR factor is defined as the percent reduction in ABC thickness for a reinforced pavement compared to the thickness of the same pavement without reinforcement. It is important to note that the BCR factor is applied to the ABC layer thickness only, and not to the thickness of the asphalt.

The extension of pavement life is reflected by the Traffic Benefit Ratio (TBR). The TBR compares the number of vehicle loads to reach a specific failure state (rut depth) on a reinforced versus an unreinforced pavement section.

Base/Subbase Reinforcement Mechanisms

Four suggested mechanisms describe how a geosynthetic provides base/subbase reinforcement within the pavement section (Berg et al. 2000). The first mechanism is lateral confinement, where there is shear interaction between the geosynthetic and the aggregate; this interaction prevents lateral spreading of the base aggregate. The second mechanism is an increased stiffness in the base course aggregate due to the interaction between the aggregate and the geosynthetic; the increased stiffness leads to lower vertical strains, and potentially lower vertical deformations in the base course aggregate. The third mechanism is a spreading of the load, which results in better stress distribution on the subgrade. The fourth mechanism is reduced shear strain in the subgrade due to tensile loading to the geosynthetic.

Geosynthetics are also used for separation to minimize intrusion of subgrade soil into the ABC or subbase. A geogrid placed at the interface between the ABC and the subgrade can also provide a separation function. In this situation, the geogrid can prevent the ABC from moving downward into or penetrating the subgrade; however, it cannot prevent the subgrade from contaminating the ABC by pumping and migration of fines. A separation geotextile, on the other hand, can both prevent the ABC from moving downward into or penetrating the subgrade and also prevent the subgrade from contaminating the ABC.

REVIEW OF DESIGN GUIDELINES

The first step in developing the design guidelines was to identify and review other available design guidelines for using geosynthetics for base/subbase reinforcement. The objectives of reviewing other design guidelines were to:

- Determine the state of the practice.
- Identify similarities between design guidelines and methods.
- Identify elements of design guidelines that may be applicable to ADOT.
- Make recommendations for new design guidelines for ADOT.

Design guidelines from several sources were reviewed to determine current industry practices for the use of geosynthetics for base/subbase reinforcement. These sources include:

- FHWA.
- AASHTO.
- Geosynthetic Materials Association (GMA).
- Caltrans.
- FAA.
- USACE.

These design guidelines were selected because they represent key entities, including federal and state government, as well as the geosynthetics industry itself. A description of each of the design guidelines follows. In addition, the existing ADOT design method was reviewed and summarized for reference.

Soil Properties Used in Design Guidelines

The design guidelines that were reviewed used different soil strength properties to determine whether base/subbase reinforcement was appropriate. These properties included California Bearing Ratio (CBR), Subgrade Modulus (M_r), and soil Resistance Value (R-Value). M_r is the definitive engineering property used to characterize subgrade soil. However, M_r testing can be costly and time consuming. As a result, CBR and R-Value testing are often used as a substitute to estimate M_r. An M_r value can be calculated from a measured CBR or R-Value by using a correlation equation.

NCHRP 1-37A developed equations relating M_r to CBR and to R-Value. ADOT also has developed an equation relating M_r to R-Value. Caltrans identifies corresponding R-Values for specific M_r values in their design guidelines.

ADOT and Caltrans both use the AASHTO T-190 test method for measuring R-Value. However, ADOT and Caltrans have different correlations for estimating a M_r from the measured R-Value. Caltrans is much more conservative, in that it correlates a lower M_r for a given R-Value than ADOT does. The ADOT equation includes the Seasonal Variation Factor (SVF), which results in different calculated M_r values depending on the value of the SVF.

Appendix P includes equations, graphs, and a table correlating the properties.

ADOT Preliminary Engineering and Design Manual

The existing ADOT design method for flexible pavements is documented in Chapter 2 of the *Materials Preliminary Engineering and Design Manual* (MPEDM) (ADOT 1992). ADOT follows the AASHTO *Guide for Design of Pavement Structures* (1986) method. The AASHTO design method is an empirical design method. AASHTO developed pavement design equations based on observed effects of different traffic loading on various pavement sections. The equations and methodology are included in Appendix O for reference.

ADOT TAC members report that ADOT is also using the *Mechanistic-Empirical Pavement Design Guide* (MEPDG) in parallel with the AASHTO design method (the 1986/1993 Design Guide and the MEPDG are both AASHTO methods). The MEPDG method is based on both mechanistic and empirical input. MEPDG pavement designs can be computed using the AASHTOWare Pavement-ME software.

ADOT addresses the use of geosynthetics in three places: the MPEDM, the Standard Specifications, and the *Construction Manual*. The MPEDM states that: “For purposes of the design the mean subgrade R-Value should be increased by 10 when a geosynthetic is used.” (Section G.1.j) However, the MPEDM does not distinguish between geogrid and geotextiles or give any guidance on when to use geosynthetics.

ADOT Standard Specification Section 306, *Geogrid Base Reinforcement*, addresses the use of geogrid for base reinforcement. Section 306 of the ADOT Construction Manual also addresses geogrids and refers to the ADOT MPEDM.

The MPEDM also notes that a “Separation Geotextile Fabric may be used” to “improve the separation between the base and subgrade materials and avoid loss of fine material into the base.” It is important to note that the benefits of the geosynthetic’s performance depend on correct installation as well as proper design. These are the only ADOT guidelines currently established for the use of geosynthetics in pavement design.

According to ADOT TAC members, the primary application of the existing ADOT design method has been to use geosynthetic reinforcement (typically biaxial geogrid) to improve the R-value of weaker subgrades to at least 20 for design of the pavement section. Geosynthetic reinforcement has not been used for the specific purpose of reducing the thickness of ABC. However, the practice of using geosynthetic reinforcement to improve the R-value has the effect of reducing the Structural Number (SN) in the design pavement section. The lower SN results in a reduced pavement section thickness, which can be applied to ABC thickness and/or AC thickness. ADOT staff has indicated that using geosynthetic reinforcement to further reduce the thickness of ABC or to reduce the ABC thickness for stronger subgrades may not be cost-effective due to the low cost of ABC in Arizona.

ADOT has not performed any performance-related studies or testing to verify the performance of their design method for using geosynthetics. However, ADOT TAC members suggest that the existing design method has been used for more than 20 years and that no pavement failures have been experienced that could be attributed to this design method. Therefore, ADOT TAC members are confident in the design method and the results that it produces.

GMA White Paper II - Geosynthetic Reinforcement of the Aggregate Base/Subbase Courses of Pavement Structures

The Geosynthetic Materials Association (GMA) sponsored a report to assess the value added when geosynthetics are used to reinforce the aggregate base within pavement structures (Berg et al. 2000). The report focuses on reviewing existing literature, research, laboratory tests, and field tests related to the use of geosynthetics for base reinforcement in North America. The objectives of the review were to summarize benefits, evaluate life-cycle cost savings, recommend design procedures, and recommend practices for specification of geosynthetics for base reinforcement.

The GMA White Paper II includes a literature review of laboratory and field studies related to geosynthetic reinforcement of aggregate base/subbase courses for pavements. It is a follow-up to a similar report, GMA White Paper I (Richardson 1998).

The functions of geosynthetics in a pavement section—such as separation, filtration, lateral drainage, reinforcement, lateral restraint, bearing capacity increase, and tensile membrane support—are discussed. Separation, filtration, and lateral drainage are largely functions provided by geotextiles. Reinforcement, lateral restraint, bearing capacity increase, and tensile membrane support may be provided by geotextiles, geogrids, or geotextile/geogrid composites.

The applicability of geosynthetics is generally based on the strength of the subgrade soils beneath the pavement section. Subgrade strength is classified as firm, moderate, or low. A firm subgrade is defined as a subgrade with a CBR value greater than 8. A moderate subgrade is defined as a subgrade with a CBR value in the range of 3 to 8. A low subgrade is defined as a subgrade with a CBR less than 3.

GMA White Paper II (Berg et al. 2000) contains design procedures for base (or subbase) reinforcement. The design procedures are based on empirically derived factors for extending pavement design life or reducing the pavement section thickness. Three factors are identified: the TBR, the BCR ratio, and the Layer Coefficient Ratio (LCR). The TBR is also known as the Traffic Improvement Factor.

The TBR can be expressed using the following equation (Equation 1):

$$TBR = \frac{N_R}{N_U} \quad \text{(Eq. 1)}$$

Where:

N_R = The number of loads to reach a specific failure state (rut depth) on a reinforced pavement section

N_U = The number of loads to reach a specific failure state (rut depth) on an unreinforced pavement section

The TBR can be applied to the AASHTO design equation to extend pavement life as follows:

$$W_{18}(reinforced) = TBR * W_{18}(unreinforced) \quad \text{(Eq. 2)}$$

Where:

W_{18} = The number 18 kip equivalent single axle loads (ESALs)

TBR values for design must be obtained from previously conducted laboratory or field tests. TBR values are specific to the laboratory or field test conditions, which include the geosynthetic material used. In the GMA White Paper II (Berg et al. 2000), TBR values ranging from 1 to 220 were developed from the test sections reviewed containing geotextiles.

The BCR can be expressed using Equation 3:

$$BCR = \frac{T_R}{T_U} \quad \text{(Eq. 3)}$$

Where:

T_R = Thickness of base-course for reinforced pavement section

T_U = Thickness of base-course for unreinforced pavement section

The BCR can be applied to the AASHTO design equation (Equation 4) for the SN as follows:

$$SN = (a \times d)_{hma} + BCR(a \times d \times m)_{base} + (a \times d \times m)_{subbase} \quad \text{(Eq. 4)}$$

Where:

a	=	The structural layer coefficient
d	=	The layer thickness
m	=	The drainage coefficient

Different BCR values have been identified through laboratory tests and field tests. BCR values are specific to the conditions and materials tested, and are not widely applicable.

The benefit of geosynthetic use may be measured by using a BCR (the percent reduction in the reinforced base thickness from the unreinforced thickness to reach the same defined failure state). Another method of modifying the pavement section would be to multiply the base layer coefficient by a layer coefficient ratio (LCR). This value is back-calculated from the number of load cycles on a reinforced section that reach a defined failure state compared to the number of load cycles on an unreinforced section, with the same layer thicknesses, that reach the same defined failure state.

GMA White Paper II (Berg et al. 2000) begins with a summary of studies that have been performed utilizing geosynthetics for base reinforcement. The types of geosynthetics studied included geotextile, geogrids, and geogrid/geotextile composites. Numerous test section studies are shown in tables, with the testing parameters, test section layers and properties, and geosynthetics properties provided. A description of the location of the geosynthetic with respect to the base course layer is also provided. Finally, the benefit determined for extension of life (TBR) and base course reduction (BCR) using geotextiles and geogrids are presented for each study.

A table summarizing the study review shows many geosynthetic, subgrade, base, and pavement conditions that result in the greatest benefit provided by the geosynthetic in reinforcement. Geotextiles or geotextile/geogrid composites appeared to perform best when the CBR was less than 3, primarily in a separation function and for stabilization of the subgrade. When the CBR was in the range of 3 to 8, the reinforcement function of the base course was more important. For firmer subgrades with a CBR greater than 8, the reinforcement function was a known benefit only under certain conditions. Table 4.1, “Qualitative Review of Reinforcement Application Potential for Paved Permanent Road,” shows how geotextiles, geogrids, and geogrid/geotextile composites should be utilized in the pavement section to provide the most benefit. A summary of available design approaches and procedures for paved permanent road design includes base reinforcement, subgrade restraint, and separation/filtration/drainage.

A process for cost analysis is presented. Two strategies are suggested: a life-cycle cost analysis and an initial cost comparison. A life-cycle cost analysis typically shows a greater benefit. The life-cycle cost analysis uses the AASHTO DARWIN computer program. Examples of each type of cost analysis are presented in the paper. The full data input and cost analysis is included in Appendix C of the white paper.

A discussion of material properties important to geotextiles and geogrids is presented in GMA White Paper II (Berg et al. 2000). The geotextile properties are fairly well defined for separation and stabilization in AASHTO M288. Although characteristic properties for a geotextile in a base reinforcement application are provided, no values for these properties are given. Similarly, the properties that appear important for a geogrid in a base reinforcement application are noted, but no actual values for these properties are provided. The sample specifications in Appendix D of the white paper also leave the values for material properties blank in most instances except for those already defined in AASHTO M288.

The paper goes through a step-by-step design procedure for base reinforcement, but does not provide values for BCR, TBR, or LCR. It states that these values must be obtained from laboratory test results that have been correlated from field tests. It shows how to do the design, but it gives no accepted design values for BCR, TBR, or LCR. For separation and filtration, the numbers are defined by an excerpt of AASHTO M288 in Appendix B of the white paper. It also provides a similar step-by-step design procedure for subgrade restraint (subgrade stabilization), but this is primarily for using less base material for subgrade stabilization and does not impact the actual pavement structure or thickness design.

As a result, the paper recognizes a distinction between base reinforcement and subgrade restraint/stabilization. Design procedures and specifications vary between these two functions. Base reinforcement can extend the performance period of a pavement, reduce the base thickness, or create a combination of the two. Subgrade restraint/stabilization is used to reduce the aggregate thickness and depth of over-excavation for pavement construction over weak, very moist subgrades.

The paper states that the reason more specific design procedures are not provided is the variability of geosynthetics and the variability in how they work in different design configurations. As a result, a generic design procedure and generic material specification are not provided.

The paper presents a work plan in its Appendix E for evaluating geosynthetics in base reinforcement applications utilizing a test section with accelerated traffic loadings. A plan for quality control and documentation during and after test section construction is provided. This process could be utilized for full-scale roadway construction where sections are constructed with and without geogrid or geosynthetics for long-term evaluation. A work plan should be utilized for evaluation of every full-scale installation to better document the benefit of using geosynthetics in pavement reinforcement applications.

National Highway Institute (NHI) Course No. 132013, FHWA NHI-07-092 - Geosynthetic Design and Construction Guidelines (FHWA 2008)

This manual was developed to provide an overview of geosynthetics materials and their applications. The manual is an updated version of FHWA NHI-95-038 (updated in 1998). The manual addresses several applications including drainage, erosion control, runoff and sediment control, roadways and pavements, pavement overlays, reinforced embankments, reinforced slopes, mechanically stabilized earth retaining walls, and geomembranes. The manual includes step-by-step design procedures for some applications.

Section 5 of the manual is devoted to the use of geosynthetics in roadways and pavements. It discusses the applicability and benefits of geosynthetics and provides design guidelines for geotextiles and geogrids in temporary, paved, and unpaved roadways. Section 5.2 identifies subgrade and soil conditions in which geosynthetics are useful.

Section 5.6 of the manual provides design guidelines for the use of geotextiles in permanent paved roadways. Geoxtextiles can be used to provide separation between the subgrade and base. (Geogrids are not as effective at providing separation.) A separation geotextile can prevent base aggregate from penetrating into the subgrade; it can also prevent subgrade fines from pumping or migrating into the base. The manual states that pavement failure may occur from the intrusion of subgrade soils into the granular base. Consequently, the use of a separation geotextile would be beneficial in the pavement section over the long term. Section 5.6-1 of the manual lists a design method for using a separation geotextile in a pavement design. The design method is based on the subgrade conditions, the subgrade particle size, and the required survivability of the geotextile. The manual provides tables designed to assist with selecting the construction survivability of the geotextile separation fabric.

Various design guidelines for unpaved roadways or temporary roads are provided, based on USFS design guidelines. These guidelines are useful for subgrade stabilization during construction, but not for a permanent paved roadway.

The manual's Section 5.9-3, *Geogrid Reinforcement*, states that a geogrid specification for reinforcement of pavement structures is not available. This is due to several considerations, including:

- A lack of understanding of the mechanistic benefits of geogrid reinforcement.
- The absence of a generic design procedure.
- The lack of a clear definition of the function of the geogrid in pavement reinforcement.
- An inability to measure the contribution of geogrid reinforcement to the pavement structure with non-destructive testing methods such as falling weight deflectometer (FWD), and the long-term nature of measuring the benefit of the geogrid over the pavement life.

The manual provides a useful reference regarding design guidelines for geosynthetics. It addresses the question of which geosynthetic is appropriate for a particular application and describes how to effectively use the geosynthetic.

AASHTO Designation R 50-09 Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures

This AASHTO standard practice provides guidance for pavement designers and is limited to geotextiles, geogrids, or geogrid/geotextiles composites (AASHTO 2009). This is an empirical method because the benefits of geosynthetic-reinforced pavement structures cannot be derived theoretically. Test sections are necessary to quantify the benefits. As a result, designers need to consult references and locate a tested section similar to that which is expected in their own design. The method refers to the NHI Participant Handbook for design procedures and the GMA White Paper II (Berg et al. 2000). The target benefits should indicate whether a TBR, a BCR, or both can be identified.

Part of this procedure requires a life-cycle cost analysis for both TBR and BCR considerations. However, some of the information needed to complete a life-cycle analysis, such as benefits, may not be easily quantifiable.

After construction, it is very important to monitor or document performance, especially if reinforced and unreinforced sections are constructed during the same project. An annual assessment is recommended. In this way, knowledge of geogrid performance under different conditions will progress and design methods will improve to maximize potential benefits.

California Department of Transportation (Caltrans) Aggregate Base Enhancement with Biaxial Geogrids for Flexible Pavements, Guidelines for Project Selection and Design

This guide was prepared by Caltrans to provide guidance for the use of geogrids to reduce base course thickness in pavement design (Caltrans 2012). The guidance allows only the use of biaxial geogrids meeting Caltrans Specifications, Section 88-1.02P for Biaxial Geogrid. The geogrid must be punched and drawn (extruded) polypropylene material. The geogrid must be placed at the bottom of the base course layer.

Geogrid use is restricted to subgrades with an R-Value of less than 40 and a Plasticity Index (PI) of less than 12. The plasticity index restriction seems to be a fairly severe restriction, since most subgrade soils with an R-Value less than 40 would have a plasticity index greater than 12. Therefore, Caltrans appears to limit the use of geogrids to generally silty clayey sand to sandy silt to clay. For soils with a PI greater than or equal to 12, Caltrans recommends lime treatment of the subgrade or removal and replacement with low expansion soils, at least to the depth of potential moisture change.

It is important to note that R-Values do not directly correlate to Arizona R-Values. A chart illustrating the difference is presented in Appendix P. The chart shows the subgrade modulus (M_R) corresponding to R-Values and Arizona R-Values.

The guide presents a flow chart for the use of a subgrade enhancement geotextile depending on the gradation of the base course and the subgrade. If the subgrade is a coarse-grained soil (defined as less than 50 percent passing a No. 200 sieve) a subgrade enhancement geotextile or filter fabric is not required. However, if greater than 35 percent fines pass the No. 200 sieve, the subgrade behaves like a fine-grained soil (therefore, in this research team's opinion, a requirement for less than 35 percent passing a No. 200 sieve seems more appropriate). This is more in line with the AASHTO soil classification system for soils like A-4, A-5, A-6, and A-7, which are considered fair to poor subgrade soils with a minimum of 36 percent passing the No. 200 sieve.

A table in the guide shows the maximum percent reduction in base course thickness when a geogrid is used. This maximum is 25 percent if the R-Value is less than or equal to 20, and 20 percent if the R-Value is in the range of 20 to 40. For a base course thickness greater than 18 inches, a second layer of geogrid is recommended. The upper layer must be placed at least 6 inches beneath the final base course surface. The minimum base course thickness with biaxial geogrid beneath it is 4 inches. The subgrade's effective R-Value, including the R-Value of the subgrade after implementation of geotextiles, is the design R-Value. The design requires a pavement monitoring plan after construction to evaluate the effectiveness of the geogrid and/or subgrade enhancement geotextile.

These guidelines provide a useful point of comparison for ADOT pavement designers. The Caltrans assumptions are slightly different from ADOT's. However, there should not be a dramatic difference between the two approaches in the final design.

Caltrans Subgrade Enhancement Geosynthetic Design and Construction Guide

The purpose of this guide is to assist pavement design engineers in the selection of an appropriate Subgrade Enhancement Geotextile (SEG), including a geotextile fabric or a geogrid (Caltrans 2013). According to the guide, the SEG would be placed between the subgrade and the base course.

The guide provides the following information. For a subgrade enhancement geotextile, the primary function is filtration and separation. The geotextile prevents the subgrade from mixing with or contaminating the base course. It can also reduce the excess pore water pressure through a mechanism of filtration and drainage. Secondary mechanisms for the geotextile are lateral restraint or reinforcement. The reinforcement requires deformation of the subgrade and stretching of the geotextile to engage the tensile strength and create a "tensioned membrane."

For a subgrade enhancement geogrid, the primary function is stabilization and lateral restraint of the base materials through a process of interlocking the aggregate in the apertures of the geogrid. The level of restraint achieved is a function of the type of geogrid, the aperture opening size, and the quality and gradation of the base utilized. To maximize performance, a well graded granular base material that is sized appropriately for the aperture size of the geogrid is required. When aggregate is placed over the geogrid, it becomes confined within the apertures and is restrained from punching into the subgrade or moving laterally, thus limiting rutting on the surface. Very little deformation of the geogrid is needed to achieve lateral restraint and reinforcement. Separation and filtration are possible secondary mechanisms for a geogrid because the aggregate is confined within the apertures of the geogrid and cannot move under load.

A subgrade enhancement geotextile can be used if the R-Value is less than 20 for clayey or silty soils without limitation on the plasticity index.

A subgrade enhancement geogrid can be used if the R-Value is less than 25. For an R-Value between 25 and 40, the designer may consider using a geogrid for base reinforcement. Use of geogrid is not recommended unless the aggregate material meets the following filter criteria: D15 of base material/D85 of subgrade < 5 and D50 of base material/D50 of subgrade <25, where D15, D85, and D50 are grain sizes for which 15 percent, 85 percent, and 50 percent of the material is smaller than these sieve sizes, respectively.

If the base material does not meet the above natural filter criteria, geotextiles that meet both separation and stabilization requirements are recommended.

A geotextile or geogrid should not be utilized if the R-Value for the subgrade soil exceeds 40.

The guide provides a flow chart to help designers make the correct choice in the design process. The potential economic and intrinsic benefits should also be investigated.

There are five possible choices of geotextiles: Classes A1, A2, B1, B2, and B3. There is only one type of geogrid. A1 and A2 geotextiles are woven and nonwoven, respectively. These are primarily separation geotextiles of moderate strength. B1 and B2 geotextiles are woven geotextiles of high strength. The B3 geotextile is a nonwoven geotextile of high strength. The B1, B2, and B3 high-strength geotextiles are used for separation and reinforcement. A geogrid specification is also presented in the design guidelines.

The design guidelines still consider the possibility of stabilizing soft material with lime for clay soils with a PI greater than 12. A filter analysis must also be performed on the subgrade and base course to determine whether the filtration criteria are met by the base course for a geogrid application. For applications involving drainage and filtration for geotextiles, the design engineer must verify that the permeability of the geotextile is greater than the permeability of the subgrade soil. Other considerations are:

- Recycled concrete should not be used in conjunction with a polyester geotextile fabric.
- A subgrade enhancement geotextile is not necessary if the subgrade is planned for chemical stabilization such as lime or cement.
- If a subgrade enhancement geotextile is utilized, an R-Value of less than 20 may be increased to a design R-Value of 20 in the pavement design.
- If a subgrade enhancement geogrid is utilized, an R-Value of less than 25 may be increased to a design R-Value of 25 in the pavement design. An additional geotextile separator must be used if the base course does not conform to the natural filter criteria.

Construction considerations are also provided for subgrade enhancement geotextiles and geogrids.

The guide is a practical reference that can aid ADOT pavement designers.

FAA Engineering Brief No. 49

FAA Engineering Brief No. 49 provides information and guidance on geogrid-reinforced base course (FAA 1994). The brief summarizes information from field tests conducted by the USACE. For the study, flexible pavements with and without geogrids were trafficked to failure under a 30,000-pound single-wheel axle load with a 68 psi tire pressure. The studies showed that some geogrids are capable of increasing the pavement life under traffic, while others have little or no effect on the pavement life. The document attempts to identify the physical properties a geogrid must have to enhance flexible pavement performance.

A design graph in the FAA brief shows the total pavement section, assuming 2 inches of AC plus the thickness of the base course. The y-axis shows unreinforced thickness (inches), and the x-axis shows the equivalent reinforced thickness (inches). The minimum original pavement thickness is approximately 10 inches, which has an equivalent reinforced thickness of 6 inches. The maximum original pavement thickness is 20 inches, which has an equivalent reinforced thickness of 19 inches. More benefit is shown for a thin pavement section than for a thick pavement section. Usually a thicker pavement section is required for a poor subgrade condition or for a higher expected traffic load.

Material properties that are deemed important on the basis of these studies are flexural modulus, tensile modulus, junction strength, and junction efficiency. This brief can assist ADOT pavement designers in selecting the optimum geogrid for a project.

US Army Corps of Engineers Technical Letter: ETL 1110-1-189 "Use of Geogrids in Pavement Construction"

This letter provides guidance, basic criteria, and information for the use of geogrids in the design and construction of pavements (USACE 2003). It provides the following directions.

Extruded biaxial geogrids are desired for use in pavement construction; geogrids may not be utilized for separation. The three primary uses of geogrids are as a construction aid over soft subgrade, improving or extending the projected pavement life, and reducing the structural cross-section for a given service life. Geogrids have been used for subgrade stabilization, aggregate base reinforcement, and asphalt concrete overlay reinforcement; this design procedure considers only the subgrade stabilization and base reinforcement uses. USACE recommends that for mechanical subgrade stabilization and base reinforcement of aggregate layers less than 14 inches thick, the geogrid should be placed at the bottom of the base, and a separation geotextile should be used in conjunction with the geogrid directly on the pavement subgrade. If the design base thickness is greater than or equal to 14 inches, the geogrid should be placed in the middle of the base course layer. Regardless of the placement of the geogrid, the separation fabric is always placed at the interface between the base course and the subgrade.

For subgrade with a CBR less than or equal to 0.5, the primary application is subgrade stabilization. To construct a construction platform in accordance with the design requirements for an aggregate surfaced roadway, a nonwoven geotextile is recommended for separation, and a biaxial geogrid is recommended for aggregate reinforcement. No reduction of aggregate base course is recommended.

For subgrade with a CBR in the range of 0.5 to 4.0, both subgrade stabilization and base reinforcement applications are mobilized. A nonwoven geotextile is recommended for separation, and a geogrid for reinforcement should be considered. Webster's reinforced pavement thickness equivalency chart should be used to determine the required geogrid reinforced pavement thickness. This is the same chart present in FAA Engineering Brief No. 49 (FAA 1994), except the asphalt can be as much as 4 inches thick.

For subgrade with a CBR in the range of 4.0 to 8.0, a geotextile separator is not recommended unless the designer has experienced separation problems with the construction materials during previous projects. The primary application of geogrid reinforcement at higher subgrade strengths is base reinforcement. The designer should again use Webster's reinforced pavement thickness equivalency chart to determine the required geogrid-reinforced pavement thickness. A life-cycle cost should be utilized to determine the cost-effectiveness of the geogrid.

For subgrade with a CBR above 8.0, a geotextile separator is not recommended unless prior separation problems have been noted for the specific construction materials. The primary application of geogrid reinforcement at high subgrade strengths is base reinforcement. Subgrade soils with a CBR above 8.0 are outside the database used to produce Webster's chart, so test sections must be utilized to determine or define a BCR factor.

A few design examples, one for an unpaved roadway and one for flexible pavement, are presented. In addition, installation recommendations are presented for different subgrade conditions.

This document can assist ADOT pavement designers in the proper use of geogrids for a project.

Summary of Design Guidelines

Table 17 summarizes key elements of the design guidelines reviewed in this chapter.

Table 17. Summary of Design Guidelines

Entity	Includes guidelines for geotextile for separation	Design method for base reinforcement
ADOT (ADOT 1992)	No	Increase R-Value by 10 when a geosynthetic is used.
GMA White Paper II (Berg et al. 2000)	Yes	Use BCR or TBR factors as identified from previous studies.
FHWA (FHWA 2008)	Yes	Use BCR or TBR factors as identified from previous studies.
AASHTO (AASHTO 2009)	No	Requires test sections to quantify the benefits.
CALTRANS (Caltrans 2012) (Caltrans 2013)	Yes	Aggregate Base Enhancement: Geogrid use is restricted to subgrades with an R-Value of less than 40 and a Plasticity Index of less than 12. The use of a subgrade enhancement geotextile depends on the gradation of the base course and the subgrade.
FAA (FAA 1994)	No	A design graph shows the total pavement section, assuming 2 inches of AC plus the thickness of the base course. The chart y-axis is unreinforced thickness (inches), and the chart x-axis is equivalent reinforced thickness (inches).
USACE (USACE 2003)	Yes	Geogrid should be placed at the bottom of the base for aggregate layers less than 14 inches in thickness; for design base thickness greater than or equal to 14 inches, the geogrid should be placed in the middle of the base course layer.

REVIEW OF PERFORMANCE-RELATED STUDIES

Field studies related to the performance of geosynthetics in pavement design were reviewed with the intent of assessing the applicability and effectiveness of the various design guidelines. Although guidelines for the use of geosynthetics are based on empirical data, none of the design guidelines reviewed presented clear a rationale for the requirements specified.

The results of geogrid field studies provide a useful reference for assessing the appropriateness of geosynthetic specifications. Several of the more relevant studies are summarized in this section. The focus was on studies that evaluated the effectiveness of geosynthetics in pavements related to the TBR and BCR.

North Dakota DOT

Report No. 1 (Kuhlmann and Marquart 1998)

This report presents the results of a study on two geogrid test sections on roadways with weak subgrade in North Dakota. The objective of the study was to evaluate the effectiveness of geogrid in reducing the subcut or ABC thickness required for the roadway. This roadway had experienced significant rutting and patching over its previous life, and the roadway was essentially being reconstructed. The normal practice was to improve areas of weak subgrade by removing the weak soils and replacing them with granular material or ABC.

The project was approximately 11 miles in length in both directions. Of this, approximately 5,000 feet comprised the test section, which consisted of a control section and Test Sections A and B. The original design was not utilized since the subgrade was softer and weaker than expected. As a result, revised sections were utilized. The revised sections were thicker both for the test sections and the control section.

Evaluations were performed on a yearly basis starting with 1992 and continuing to 1996. The evaluation consisted of rut measurement, measurement of transverse cracking, measure of deflection by FWD, and calculation of subgrade and base modulus utilizing the FWD data.

This report showed no evidence of a benefit leading to a reduction of the base course thickness from using geogrid within or below the roadway base. Increase in the thickness of the base did show evidence of benefit in every case (Kuhlmann and Marquart 1998).

Report No. 2 (Marquart 2004)

The report describes the construction of control and test sections for evaluation of geogrid base reinforcement on a highway in North Dakota. The geogrid was placed within the base course for two test sections. The test sections were compared to a standard unreinforced pavement section for a period of 10 years, monitoring pavement distress and condition, tracking maintenance costs, and performing FWD tests. The study sections are the same as in the ND 91-01 study that was previously described.

The objective of the study was to determine whether the TBR of 3, in accordance with the FAA and Army Corps of Engineers design process, was applicable.

Three different test sections were installed as follows:

- Control Section 1 consisted of 5.5 inches of AC over 18 inches of blended base.

- Section 2 consisted of 5.5 inches of AC over 18 inches of blended base, with the geogrid located 6 inches below the top of the blended base.
- Section 3 consisted of 5.5 inches of AC over 12 inches of blended base, with the geogrid located 6 inches below the top of the blended base.

The geogrid utilized in Sections 2 and 3 was Tensar BX1100 biaxial geogrid.

The report concludes by describing the installation of the geogrid within the blended base. However, FWD testing performed immediately after installation did not show any benefit due to the geogrid. Based on the FWD test results, it is expected that Section 3 will not perform well because of its weaker subgrade and lower blended base thickness.

Report No. 3 (Loegering, Mastel, and Marquart 2013)

This report presents the results of the fourth evaluation of control and test sections of an unreinforced control pavement section and two test sections with geogrid base reinforcement on a highway in North Dakota. The geogrid was placed within different thicknesses of base course for the test sections. The test sections were compared to a standard unreinforced pavement section for a period of 10 years, monitoring pavement distress and condition, tracking maintenance costs, and performing FWD tests. This is the fourth evaluation of the sections, eight to nine years after construction in the summer of 2003 (in 2011-2012).

Three different test sections were installed in 2003 as follows:

- The Control Section 1 consisted of 5.5 inches of AC over 18 inches of blended base.
- Section 2 consisted of 5.5 inches of AC over 18 inches of blended base, with the geogrid located 6 inches below the top of the blended base.
- Section 3 consisted of 5.5 inches of AC over 12 inches of blended base, with the geogrid located 6 inches below the top of the blended base.

The geogrid utilized in Sections 2 and 3 was Tensar BX1100 biaxial geogrid.

This report concludes by describing the installation of the geogrid within the blended base. It shows that FWD testing performed immediately after and eight years after installation did not show any benefit due to the geogrid. From the initial FWD test results, it was expected that Section 3 would not perform as well because of its weaker subgrade and lower blended base thickness, and that has proven to be the case. Certainly, reducing the base thickness by 6 inches and utilizing a geogrid in Section 2 resulted in poorer pavement section performance. Installing a geogrid in an equivalent thickness of base has not resulted in a better performance in Section 2 than in unreinforced pavement Control Section 1.

Montana DOT— Geosynthetics Used as Subgrade Stabilization

A report by Cuelho, Perkins, and Morris (2014) was prepared for evaluation of geogrids and geotextiles for subgrade stabilization, but some of the information presented is also applicable to evaluation of geogrids or geotextiles for base reinforcement. Although this study is for unpaved roads, it demonstrates that higher rut levels are required in order to engage the benefit of the geosynthetic; the performance difference at low rut levels is limited.

Full-scale test sections were constructed on similar subgrades, and traffic on the sections was monitored. Seventeen 50-foot sections were constructed beside a small airport runway, 14 with a geosynthetic and three without. The average CBR of the constructed subgrade was 1.79. The test sections had an average base thickness of 10.9 inches, with the exception of two control sections where increased base thicknesses were utilized. This last aspect was most important in the evaluation of the geosynthetics with regard to base reinforcement applications, and for comparing the effect of additional base to the use of geosynthetics. In addition, the biaxial geogrid was utilized with the same base section with lower and higher subgrade stiffness than the normally constructed subgrade thickness.

The test sections were trafficked with a 45-kip 3-axle dump truck. Rut depth was measured to determine the number of truck passes to obtain rut depths from 0.5 to up to 3.5 inches. A total of 19 incremental measurements of rut depth were taken at between 0 and 740 truck passes . The information presented in the report indicated that prior to 0.5 inches of rut, there is little difference in the performance of the different test sections. The more rut that occurred, the more effective the geosynthetic became in preventing additional rut.

The report is more applicable to subgrade stabilization prior to paving than to pavement structure. The study is for an unpaved roadway, and no asphalt was utilized in the study. As a result, the actual applicability of the results of this study for a paved roadway is not known. Even with that, the most reduction of base course that could be considered by use of geosynthetic materials would be 2 inches out of the approximately 11 inches of base for the control section, or approximately 20 percent of the total thickness of base course.

US Army Engineer Research Development Center—Full-Scale Evaluation of Geogrid-Reinforced Thin Flexible Pavements

This paper documents a full-scale test section constructed and trafficked to evaluate the performance of geogrid for base reinforcement below thin, flexible pavement (Jersey et al. 2012).

A full-scale test section was constructed and subjected to traffic loading at the US Army Engineer Research and Development Center to evaluate the performance of a geogrid that was used for base reinforcement in a thin flexible pavement. Three test items—a geogrid-reinforced test item and two unreinforced control test items—were constructed under controlled conditions. The test pavements were subjected to accelerated traffic loading to evaluate the relative performance of the pavement structures. Pavement stiffness and permanent surface deformations were measured periodically throughout the testing.

The study showed that the geogrid-reinforced pavement performed better than the unreinforced control pavements did. The results were used to develop traffic benefit ratios and effective base course structural coefficients to enable comparison of the pavement structures.

It is important to note that an extremely weak subgrade soil was tested, and the results may be considerably different for a stronger subgrade soil. Although the FWD test result for the reinforced section Item A was the same as for the unreinforced Item B, and less than that for Item C, the reinforced section performed better than both unreinforced sections. This implies that the FWD test may not completely indicate or predict the performance of geogrid at the base of the pavement section. This study agrees that 1 inch of rut on the pavement surface is considered a failure.

SUMMARY OF STUDIES

The studies reviewed and the conclusions are summarized in Table 18.

Table 18. Summary of Studies Reviewed

Study	Conclusions
ND 91-01	Does not show any benefit from the use of geogrid.
ND 2002-01 Construction Report	FWD results did not show any benefit from using a geogrid.
ND 2002-01 Fourth Evaluation	Does not show any benefit from the use of a geogrid. Study indicates a possible negative effect of using the BCR concept.
FHWA/MT-14-002	Benefit of using geosynthetic increases with rut depths. Rut depths greater than acceptable may be required in order to engage benefit of geosynthetic.
TRB No. 2310	Shows a clear benefit to using a geogrid. Study results have to be questioned due to the change in the method of traffic loading (i.e., single vehicle versus tandem axis) during the study. AC thickness used in the study is much thinner than typically used by ADOT. Subgrade strengths were much lower than ADOT would allow under a pavement.

Although the studies do not indicate a clear and quantifiable benefit, ADOT has been using geogrid for pavement reinforcement and has experienced satisfactory results with the existing design process.

EVALUATION OF CURRENT ADOT GEOGRID DESIGN PROCESS

Section 202.02, *Flexible Pavement Design*, of the ADOT MPEDM specifies the method of incorporating geosynthetic material into the pavement design process. Subsection G.1.j, which addresses the feasibility of using geosynthetics, states: “For purposes of the design the mean subgrade R-Value should be increased by 10 when a geosynthetic is used.” ADOT practice has been to consider geogrids for the purpose of increasing the subgrade R value where the geogrid is placed at bottom of the ABC layer.

Geotextile fabric has not been used for this purpose. However, geotextile is sometimes used with a geogrid for separation, although there is no design procedure for its use.

Both the AASHTO GMA White Paper II, *Geosynthetic Reinforcement of the Aggregate Base/Subbase Courses of Pavement Structures* (Berg et al. 2000), and AASHTO Designation R 50-09, *Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures* (AASHTO 2009), recommend utilizing a TBR or BCR percentage to determine the benefit of utilizing geogrid in base reinforcement applications for pavement design. Therefore, it is useful to evaluate ADOT's guidelines with respect to the TBR or BCR.

The current ADOT MPEDM was followed in determining the required pavement design for three types of roadways: interstate rural freeways, primary rural highways, and secondary rural highways. All of these roadways will utilize a flexible pavement design process. Actual traffic projections from ADOT Traffic Planning were utilized in the analysis.

The Flexible Pavement Design procedure for ADOT is based on the AASHTO basic design equation, which is presented on Page 80 of the ADOT MPEDM. The Resilient Modulus of the subgrade soil is a factor in the equation. Other factors that have an impact on the pavement design are the predicted 18-kip equivalent single-axle load applications over the design period, the standard normal deviate which is based on the level of reliability for the design, the combined standard error, and the difference in the pavement serviceability index, from initial to terminal at the end of the design period. ADOT TAC members report that ADOT has been using a value of 0.35 for the combined standard error. The Resilient Modulus is determined from an equation on Page 87 of the ADOT MPEDM, utilizing the Mean R-Value and seasonal variation factor (SVF), where the SVF is taken from Figure 202.02-1 and Table 202.02-4 for different cities on Pages 88-92. The maximum Resilient Modulus permitted by ADOT is 26,000. Increasing the R-Value by 10 has the effect of increasing the value of the Resilient Modulus utilized in the design equation, which results in a decrease in the required Structural Number (SN) for the pavement design. For purposes of this design analysis, the structural coefficients listed on Page 96, Table 202.02-6, of the ADOT MPEDM were utilized for comparison of designs. The structural coefficient assumed for AC was 0.44, and the structural coefficient for Aggregate Base (AB) was assumed to be 0.14.

Using the current ADOT Flexible pavement design procedure, the effect of increasing the Mean R-Value by 10 by using geogrid at the bottom of the base course was analyzed for different roadway and traffic applications for assumed soil R-Values ranging from 6 to 40. Typically, ADOT uses the design procedure only for soils with R-Values up to 20. The purpose of analyzing the design procedure over this range of R-Values is to evaluate how the design procedure affects the pavement design for a wide range of R-Values. The lower R-Value of 6 is correlated to a CBR of 3 based on the NCHRP 1-37A and ADOT equations discussed in Appendix P.

Five design examples were evaluated to determine the percent reduction in ABC calculated using the ADOT design method. Each design example was selected to represent different traffic conditions and locations within the state. The percent reduction in ABC thickness resulting from the use of geogrid reinforcement was calculated for different R-Values and AC thicknesses for each design example. The design examples follow.

The first example is for Interstate 10 (I-10) near Casa Grande, from mile-post (MP) 185 to MP 191. The following assumptions were made:

- SVF = 1.0
- Reliability = 99 percent
- Δ Pavement Serviceability Index (PSI) = 1.2
- Traffic load is 45,000 average daily traffic (ADT) in both directions with 70 percent of the traffic assumed in one direction in the design lane
- 2.3 percent annual growth from 2010 to 2030
- Vehicle mix is Automobiles–85 percent, Light to Medium Trucks–5.0 percent, Heavy Trucks–10.0 percent

The reduced ABC thickness that would be achieved is shown in Table 19.

Table 19. ABC Reduction for I-10 near Casa Grande

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)
6	7.56	8	29	-	-	
16 w/geogrid	6.13	8	18.5	10.5	36.2	18.9
6	7.56	9	26	-	-	
16 w/geogrid	6.13	9	15.5	10.5	40.4	18.9
6	7.56	10	22.5	-	-	
16 w/geogrid	6.13	10	12.5	10	44.4	18.9
6	7.56	11	19.5	-	-	
16 w/geogrid	6.13	11	9	10.5	53.9	18.9
6	7.56	12	16.5	-	-	
16 w/geogrid	6.13	12	6	10.5	63.6	18.9
10	6.84	8	24	-	-	
20 w/geogrid	5.78	8	16	8	29.6	15.5
10	6.84	9	20.5	-	-	
20 w/geogrid	5.78	9	13	7.5	36.6	15.5
10	6.84	10	17.5	-	-	
20 w/geogrid	5.78	10	10	7.5	42.9	15.5
10	6.84	11	14.5	-	-	
20 w/geogrid	5.78	11	7	7.5	51.7	15.5
15	6.13	7	22	-	-	
25 w/geogrid	5.36	7	16.5	5.5	25.0	12.6
15	6.13	8	18.5	-	-	
25 w/geogrid	5.36	8	13	5.5	29.7	12.6
15	6.13	9	15.5	-	-	
25 w/geogrid	5.36	9	10	5.5	35.5	12.6
15	6.13	10	12.5	-	-	
25 w/geogrid	5.36	10	7	5.5	44.0	12.6
20	5.78	6	22.5	-	-	
30 w/geogrid	5.02	6	17	5.5	24.4	13.2
20	5.78	7	19.5	-	-	
30 w/geogrid	5.02	7	14	5.5	28.20	13.2
20	5.78	8	16	-	-	
30 w/geogrid	5.02	8	10.5	5.5	34.4	13.2
20	5.78	9	13	-	-	
30 w/geogrid	5.02	9	7.5	5.5	42.3	13.2
25	5.36	5	22.5	-	-	
35 w/geogrid	4.75	5	18	4.5	20.0	11.4
25	5.36	6	19.5	-	-	
35 w/geogrid	4.75	6	15	4.5	23.1	11.4
25	5.36	7	16.5	-	-	
35 w/geogrid	4.75	7	12	4.5	27.3	11.4
25	5.36	8	13	-	-	
35 w/geogrid	4.75	8	9	5	38.5	11.4

Table 19. ABC Reduction for I-10 near Casa Grande (continued)

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)
30	5.02	5	20	-	-	
40 w/geogrid	4.51	5	16.5	3.5	17.5	10.2
30	5.02	6	17	-	-	
40 w/geogrid	4.51	6	13.5	3.5	20.6	10.2
30	5.02	7	14	-	-	
40 w/geogrid	4.51	7	10	4.0	28.6	10.2
30	5.02	8	10.5	-	-	
40 w/geogrid	4.51	8	7	3.5	33.3	10.2
35	4.75	5	18	-	-	
42 w/geogrid*	4.37	5	15.5	2.5	13.9	8.0
35	4.75	6	15	-	-	
42 w/geogrid*	4.37	6	12.5	2.5	16.7	8.0
35	4.75	7	12	-	-	
42 w/geogrid*	4.37	7	9	3	25.0	8.0
35	4.75	8	9	-	-	
42 w/geogrid*	4.37	8	6	3	33.3	8.0
40	4.51	5	16.5	-	-	
42 w/geogrid*	4.37	5	15.5	1	6.1	3.1
40	4.51	6	13.5	-	-	
42 w/geogrid*	4.37	6	12.5	1	7.4	3.1
40	4.51	7	10	-	-	
42 w/geogrid*	4.37	7	9	1	10.0	3.1
40	4.51	7	7	-	-	
42 w/geogrid*	4.37	7	6	1	14.3	3.1

* Limited to a maximum resilient modulus M_r of 26,000, which is equivalent to an ADOT R-Value of 42 for an SVF of 1.0.

The next example is for I-10 near San Simon, from MP 382 to MP 391. The following assumptions were made:

- SVF = 1.6
- Reliability = 99 percent
- Δ PSI = 1.2
- Traffic load is 12,900 ADT in both directions with 70 percent of the traffic assumed in one direction in the design lane
- 0.8 percent annual growth from 2010 to 2030
- Vehicle mix is Automobiles–63 percent, Light to Medium Trucks–5.0 percent, Heavy Trucks–32.0 percent

The reduced ABC thickness that would be achieved is shown in Table 20.

Table 20. ABC Reduction for I-10 near San Simon

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)
6	7.63	9	26	-	-	
16 w/geogrid	6.19	9	16	10	38.5	18.9
6	7.63	10	23	-	-	
16 w/geogrid	6.19	10	13	10	43.5	18.9
6	7.63	11	20	-	-	
16 w/geogrid	6.19	11	9.5	10.5	52.5	18.9
6	7.63	12	17	-	-	
16 w/geogrid	6.19	12	6.5	10.5	61.8	18.9
10	7.15	8	26	-	-	
20 w/geogrid	5.96	8	17.5	8.5	32.7	16.6
10	7.15	9	23	-	-	
20 w/geogrid	5.96	9	14.5	8.5	37.0	16.6
10	7.15	10	19.5	-	-	
20 w/geogrid	5.96	10	11	8.5	43.6	16.6
10	7.15	11	16.5	-	-	
20 w/geogrid	5.96	11	8	8.5	51.5	16.6
15	6.45	7	24	-	-	
25 w/geogrid	5.58	7	18	6	25.0	13.5
15	6.45	8	21	-	-	
25 w/geogrid	5.58	8	14.5	6.5	31./0	13.5
15	6.45	9	18	-	-	
25 w/geogrid	5.58	9	11.5	6.5	36.1	13.5
15	6.45	10	14.5	-	-	
25 w/geogrid	5.58	10	8.5	6	41.4	13.5
20	5.96	7	20.5	-	-	
30 w/geogrid	5.27	7	15.5	5	24.4	11.6
20	5.96	8	17.5	-	-	
30 w/geogrid	5.27	8	12.5	5	28.6	11.6
20	5.96	9	14.5	-	-	
30 w/geogrid	5.27	9	9.5	5	34.5	11.6
20	5.96	10	11	-	-	
30 w/geogrid	5.27	10	6	5	45.5	11.6
25	5.58	6	21	-	-	
35 w/geogrid	4.89	6	16	5	23.8	12.4
25	5.58	7	18	-	-	
35 w/geogrid	4.89	7	13	5	27.8	12.4
25	5.58	8	14.5	-	-	
35 w/geogrid	4.89	8	10	4.5	31.0	12.4
25	5.58	9	11.5	-	-	
35 w/geogrid	4.89	9	6.5	5	43.5	12.4

Table 20. ABC Reduction for I-10 near San Simon (continued)

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)
30	5.27	5	22	-	-	
40 w/geogrid	4.68	5	17.5	4.5	20.5	11.2
30	5.27	6	19	-	-	
40 w/geogrid	4.68	6	14.5	4.5	23.7	11.2
30	5.27	7	15.5	-	-	
40 w/geogrid	4.68	7	11.5	4	25.8	11.2
30	5.27	8	12.5	-	-	
40 w/geogrid	4.68	8	8.5	4	32.0	11.2
35	4.89	5	19	-	-	
45 w/geogrid	4.41	5	16	3	15.8	9.8
35	4.89	6	16	-	-	
45 w/geogrid	4.41	6	13	3	18.8	9.8
35	4.89	7	13	-	-	
45 w/geogrid	4.41	7	9.5	3.5	26.9	9.8
35	4.89	8	10	-	-	
45 w/geogrid	4.41	8	6.5	3.5	35.0	9.8
40	4.68	5	17.5	-	-	
50 w/geogrid	4.17	5	14	4	19.0	10.9
40	4.68	6	14.5	-	-	
50 w/geogrid	4.17	6	11	3.5	20.0	10.9
40	4.68	7	11.5	-	-	
50 w/geogrid	4.17	7	8	4	27.6	10.9

The next example is for US-70 near Thatcher, from MP 332 to MP 336. The following assumptions were made:

- SVF = 1.6
- Reliability = 90 percent
- Δ PSI = 1.5
- Traffic load is 8,846 ADT in both directions with 100 percent of the traffic assumed in one direction in the design lane
- 1.4 percent annual growth from 2010 to 2030
- Vehicle mix is Automobiles–92.5 percent, Light to Medium Trucks–4.4 percent, Heavy Trucks–3.1 percent

The reduced ABC thickness that would be achieved is shown in Table 21.

Table 21. ABC Reduction for U.S. 70 near Thatcher

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)
6	5.17	4	24.5	-	-	
16 w/geogrid	4.03	4	16	7.5	30.6	22.1
6	5.17	5	21	-	-	
16 w/geogrid	4.03	5	13	8	38.0	22.1
6	5.17	6	18	-	-	
16 w/geogrid	4.03	6	10	8	44.4	22.1
6	5.17	7	15	-	-	
16 w/geogrid	4.03	7	7	8	53.3	22.1
10	4.79	4	21.5	-	-	
20 w/geogrid	3.85	4	15	6.5	30.2	19.6
10	4.79	5	18.5	-	-	
20 w/geogrid	3.85	5	12	6.5	35.1	19.6
10	4.79	6	15.5	-	-	
20 w/geogrid	3.85	6	8.5	7	45.2	19.6
15	4.24	4	17.5	-	-	
25 w/geogrid	3.56	4	13	4.5	25.7	16.0
15	4.24	5	14.5	-	-	
25 w/geogrid	3.56	5	9.5	5	34.5	16.0
15	4.24	6	11.5	-	-	
25 w/geogrid	3.56	6	6.5	5	43.5	16.0
20	3.85	4	15	-	-	
30 w/geogrid	3.33	4	11	4	26.7	13.5
20	3.85	5	12	-	-	
30 w/geogrid	3.33	5	8	4	33.3	13.5
25	3.56	4	13	-	-	
35 w/geogrid	3.06	4	9.5	3.5	26.9	14.0
30	3.33	4	11	-	-	
40 w/geogrid	2.92	4	8.5	2.5	22.7	12.3
35	3.06	4	9.5	-	-	
45 w/geogrid	2.75	4	7	2.5	26.3	10.1
40	2.92	4	8.5	-	-	
50 w/geogrid	2.74	4	6	2.5	29.4	6.2

The next example is for State Route 264 (SR 264) to Second Mesa, from MP 372 to MP 384. The following assumptions were made:

- SVF = 2.2
- Reliability = 90 percent
- Δ PSI = 1.5
- Traffic load is 2,130 ADT in both directions with 100 percent of the traffic assumed in one direction in the design lane
- 0.5 percent annual growth from 2010 to 2030
- Vehicle mix is Automobiles–80.0 percent, Light to Medium Trucks–8.0 percent, Heavy Trucks–12.0 percent

The reduced ABC thickness that would be achieved is shown in Table 22.

Table 22. ABC Reduction for SR 264 to Second Mesa

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)
6	5.23	4	25	-	-	
16 w/geogrid	4.09	4	16.5	8.5	34.0	21.8
6	5.23	5	21.5	-	-	
16 w/geogrid	4.09	5	13.5	8	37.2	21.8
6	5.23	6	18.5	-	-	
16 w/geogrid	4.09	6	10.5	8	43.2	21.8
6	5.23	7	15.5	-	-	
16 w/geogrid	4.09	7	7	8.5	54.8	21.8
10	4.74	4	21.5	-	-	
20 w/geogrid	3.66	4	13.5	8	37.2	22.8
10	4.74	5	18	-	-	
20 w/geogrid	3.66	5	10.5	7.5	41.7	22.8
10	4.74	6	15	-	-	
20 w/geogrid	3.66	6	7.5	7.5	50.0	22.8
15	4.09	4	16.5	-	-	
25 w/geogrid	3.49	4	12.5	4	24.2	14.7
15	4.09	5	13.5	-	-	
25 w/geogrid	3.49	5	9	4.5	33.3	14.7
15	4.09	6	10.5	-	-	
25 w/geogrid	3.49	6	6	4.5	42.9	14.7
20	3.66	4	13.5	-	-	
30 w/geogrid	3.22	4	10.5	3	22.2	12.0
20	3.66	5	10.5	-	-	
30 w/geogrid	3.22	5	7.5	3	28.6	12.0
25	3.49	4	12.5	-	-	
35 w/geogrid	3.01	4	9	3.5	25.9	13.8
30	3.22	4	10.5	-	-	
40 w/geogrid	2.84	4	7.5	3	28.6	11.8
35	3.01	4	9	-	-	
45 w/geogrid	2.70	4	6.5	2.5	27.8	10.3
0	2.84	4	7.5	-	-	
50 w/geogrid	2.53	4	6.0	1.5	20.0	10.9

The last example is for State Route 86 (SR 86) from Why to Quijotoa, from MP 53 to MP 96. The following assumptions were made:

- SVF = 1.2
- Reliability = 85 percent
- Δ PSI = 1.5

- Traffic load is 977 ADT in both directions with 100 percent of the traffic assumed in one direction in the design lane
- 0.2 percent annual growth from 2010 to 2030
- Vehicle mix is Automobiles–92.0 percent, Light to Medium Trucks–6.4 percent, Heavy Trucks–1.6 percent

The reduced ABC thickness that would be achieved is shown in Table 23.

Table 23. ABC Reduction for SR 86 from Why to Quijotoa

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)
6	3.10	3	12.5	-	-	
16 w/geogrid	2.45	3	8	4.5	36.0	21.0
10	2.88	3	11	-	-	
20 w/geogrid	2.21	3	6.5	4.5	40.9	23.3
15	2.45	3	8	-	-	
25 w/geogrid	2.12	3	5.5	2.5	31.3	13.5
20	2.21	3	6.5	-	-	
30 w/geogrid	2.00 min.	3	5	1.5	23.1	10.5
25	2.12	3	5.5	-	-	
35 w/geogrid	2.00 Min.	3	5	0.5	9.1	5.7
30	2.00 Min.	3	5	-	-	
40 w/geogrid	2.00 Min.	3	5	0	0.0	0.0
35	2.00 Min.	3	5	-	-	
45 w/geogrid	2.00 Min.	3	5	0	0.0	0.0
40	2.00 Min.	3	5	-	-	
50 w/geogrid	2.00 Min.	3	5	0	0.0	0.0

The above analyses of the current ADOT method of increasing the R-Value by 10 when a geogrid is utilized has a similar effect to what is stated in the reviewed literature for the BCR percentage. The BCR commonly stated in the literature is in the range of 20 to 40 percent (Zornberg 2012). The ADOT design procedure results in a different percentage of base course thickness reduction depending on the asphalt thickness used, the subgrade R-Value, the traffic volume, the reliability factor, and the ΔPSI factor, which is the difference in the initial pavement serviceability and the final pavement serviceability at the end of the pavement design life. The result is a base course reduction factor ranging from 0 to just over 50 percent.

The percentage of base course reduction was highest for the lower R-Values and generally lower for the higher R-Values. For lower R-Values, the higher required thicknesses of ABC required in pavement sections resulted in more inches of base course reduction when using geogrid for base reinforcement. For higher R-Values, the lower required thicknesses of ABC resulted in fewer inches of reduction. As a result, the most significant cost savings to be realized by utilizing geogrid for base reinforcement will be for lower R-Values and higher original base course and/or asphaltic concrete thickness.

CONCLUSIONS

ADOT Design Procedure

ADOT has an existing design procedure for geosynthetics. It is based on increasing the R-value of the subgrade when a geosynthetic is used. Increasing the R-value has the effect of reducing the required Structural Number for the pavement section, which also reduces the required thickness of the base course. It is not specified in the design procedure, but it has been ADOT practice to use a geosynthetic only when the subgrade R-Value is less than 20. The design procedures refer to "geosynthetics." It has been ADOT practice to use only geogrid in this application. The design procedure does not address the use of a geotextile for separation. However, it has been ADOT practice to use a geotextile for a separation with weak subgrades (R-Value less than 20). Subgrade gradation is also taken into consideration when determining whether to use a geotextile for separation.

Other Design Procedures

Design procedures from FHWA, AASHTO, GMA, FAA, USFS, Caltrans, and the USACE were reviewed to determine whether there are advances in design techniques that could be applied to the ADOT design procedure. The FHWA, AASHTO, GMA, and Caltrans design procedures focus on the use of BCR and TBR factors with geosynthetics to either reduce the thickness of the base course or extend the service life of the pavement section. The FHWA, GMA, and Caltrans procedures also include criteria for determining when a geotextile fabric should be used for separation between the subgrade and the base course.

The possibility of using BCR factors in the ADOT design procedure was explored. The Caltrans design procedure was the only design procedure to identify specific BCR factors that could be applied generically for different subgrade conditions. Other design procedures directed BCR factors to be selected from previous test sections that are similar to the design project. The results of the Caltrans design procedure were compared to the ADOT design procedure for five roadway design scenarios. This analysis showed that the results of the ADOT design procedure were comparable to the results of the Caltrans design procedure.

The criteria for determining when a geotextile fabric should be used for separation between the subgrade and base course were discussed with ADOT and the TAC. ADOT and the TAC were interested in adding the criteria to the ADOT design procedure. The criteria are based on the gradation of the subgrade and the base.

In general, the design procedures available are primarily empirical. This means that they are based on test results from specific design configurations. Empirical design procedures are specific to the materials and configuration from which they were derived and cannot be applied generically or widely. Because of the limitations of the available design procedures, state DOTs have been reluctant to apply them.

A mechanistic-empirical design procedure has also been developed. The design procedure is limited in its applicability because the material properties needed to input into the design procedure can be difficult to obtain. The test methods required to obtain the material properties are expensive to perform, and they are also specialized, which means that not all laboratories have the equipment to perform the tests. In addition, the empirical nature of the design procedure means that the design model has to be calibrated for specific materials and design configurations.

Field Studies

Field studies related to the performance of geosynthetics in pavement design were reviewed with the intent of assessing the applicability and effectiveness of the various design guidelines. The available guidelines for the use of geosynthetics are based solely on empirical data. However, none of the design guidelines presented a clear rationale for the requirements specified.

The results of geogrid field studies provide a useful reference for assessing the appropriateness of geosynthetic specifications. Several of the more relevant studies were reviewed, with a particular focus on studies that evaluated the effectiveness of geosynthetics in pavements related to the TBR and BCR.

The review of the field studies shows that the benefits and results realized in field studies are dependent on the conditions, materials, and design configurations tested. This supports the conclusion, as discussed in the design guidelines that were reviewed, that results of field studies are not widely applicable for design.

RECOMMENDED MODIFICATION OF ADOT MANUAL

Several recommendations are proposed for the ADOT *Materials Preliminary Engineering and Design Manual*. These recommendations are based on the current state of the practice as described in the design guidelines that were reviewed. Table 24 lists the recommendations along with the design guidelines that formed the basis for each recommendation.

Suggested modifications to the MPEDM are presented in Appendix Q in order to clarify the ADOT process for using geosynthetics.

Table 24. Summary of Proposed MPEDM Recommendations

Recommendation	Basis [1]
Type of Reinforcement Geosynthetic	
Change “geosynthetics” to “geogrid” within ADOT design procedure.	• ADOT has historically used geogrid for the purpose of base reinforcement. • GMA, FHWA, Caltrans.
Use of Geotextile for Separation	
Add design procedure for determining when geotextile is needed for separation between base and subgrade.	• GMA, FHWA, Caltrans. • A geotextile fabric can prevent the subgrade from contaminating the base and can prevent fines from the subgrade from pumping into the base. • ADOT has historically used geotextile fabric for separation for subgrades with low R-value. • ADOT is interested in expanding the use of geotextile fabric to other scenarios where it may be beneficial.
Application of Geogrid for Reinforcement	
Limit use of geogrid for reinforcement to subgrades with R-Values less than 20.	• ADOT’s experience indicates that geogrid has been successful for R-Values of 20 or less. • FHWA and GMA have determined that the structural enhancement for subgrades with CBR >8 is relatively small and uneconomical. See Appendix P for correlation of CBR and R-Value.
Restrict use of geogrids for base reinforcement over non-stabilized subgrades with mean design R-value of less than 6.	• FHWA and GMA have determined that for subgrades with CBR <3, geogrids and geotextile primarily provide separation and subgrade stabilization functions.
Minimum base course thickness for use of geogrid within pavement section must be greater than or equal to 6 inches.	• GMA, FHWA, Caltrans.
Placement of Geogrid within Pavement Section	
Geogrid should be placed at the interface between the subgrade and ABC for ABC thickness in the range of 6 to 18 inches.	• GMA, FHWA, Caltrans.

(1) GMA denotes Geosynthetics Materials Association White Paper II, *Geosynthetic Reinforcement of the Aggregate Base/Subbase Courses* (Berg et al. 2000)
FHWA denotes FHWA NHI-07-092, *Geosynthetic Design & Construction Guidelines Reference Manual* (Holtz et al. 2008)
Caltrans denotes the *Aggregate Base Enhancement with Biaxial Geogrid for Flexible Pavements Guidelines for Project Selection and Design* (Caltrans 2012)

CHAPTER 5: DESIGN GUIDELINES FOR SUBGRADE STABILIZATION

INTRODUCTION

The objective of Chapter 5 is to develop design guidelines for using geosynthetics for subgrade stabilization. This chapter includes four sections. The first discusses subgrade stabilization, including conditions where subgrade stabilization may be required. The second reviews existing design processes for subgrade stabilization using geosynthetics. The third reviews recent field performance studies for subgrade stabilization using geosynthetics. The final section presents recommendations for design guidelines based on the findings. The recommended design guidelines take into consideration the geosynthetic type, the manufacturing process, and the material (i.e., woven geotextile, nonwoven geotextile, or geogrid).

Subgrade Stabilization

The use of geotextiles or geogrids for subgrade stabilization may be an option when soft subgrade soils are encountered during the construction phase of the project. It is not usually a part of the original design process unless soft subgrade soils are anticipated during construction.

Soft subgrade presents a problem during construction because unstable and soft subgrade soils prevent proper compaction of the pavement section layers, such as ABC and asphaltic concrete, above it. If unstable subgrade is moving during the compaction process for the ABC (and especially for the asphaltic concrete), the pavement section cannot be properly constructed or compacted. If unstable subgrade soils exist at subgrade elevation prior to pavement section construction, they must be stabilized to create a stable construction platform.

Poor subgrade soils do not always mean that soft subgrade soils will be encountered during construction. If the poor subgrade soils have a moisture content that is below optimum levels for compaction, the subgrade soils do not normally need stabilization. Soft subgrade soils can occur after a significant rainfall event or a waterline leak that results in moisture infiltration into the subgrade soil. This moisture infiltration causes a poor subgrade soil to soften and become unstable. Sometimes, when an existing roadway section is removed for a reconstruction project, very moist and unstable subgrade soils are encountered because cracks in the old roadway surface allowed moisture infiltration into the roadway base course and underlying subgrade over a long period of time.

Stabilization methods that may be utilized are as follows:

1. The unstable subgrade soils may be removed and replaced with drier subgrade soils that have a moisture content below optimum to the depth necessary to obtain a stable subgrade platform. After a rainstorm event or waterline leak, this may be easy to do if the soft subgrade soils

extend to a limited depth. The presence of shallow utility lines can limit this process to a very shallow removal.

2. If no drier subgrade soils are available, the unstable subgrade soils may be removed and replaced with ABC. Since ABC is useful in bridging over underlying soft subgrade soils to a certain extent due to the angular nature of the aggregate, a limited thickness of ABC (in the range of 2 to 3 feet) may be sufficient to create a stable subgrade platform.

3. If the subgrade soils are silty, it is possible to treat the subgrade with cement, mixing it in place, usually to a depth of 12 inches. The cement dries out the subgrade soil and creates a stable subgrade platform after the cement sets. The percentage of cement could be as high as 12 percent by weight, which makes this process somewhat expensive. Shallow utility lines can affect the mixing process.

4. If the subgrade soils are clayey, it may be possible to treat the subgrade with lime, mixing it in place, usually to a depth of 12 to 18 inches. The lime tends to dry out the subgrade soil, but the subgrade needs to react with the lime for approximately five days before a stable subgrade platform is created. The percentage of lime that is usually effective is 5 percent by weight, which would lower the PI and create a modest soil compressive strength over five days. Shallow utility lines or other physical impediments can affect the mixing process.

5. Another option with soft subgrade soils is to remove a limited amount of subgrade soil, place a stabilization geogrid or geotextile over the subgrade at the bottom of the over-excavation, and add ABC back up to normal subgrade elevation. This is the method of subgrade stabilization being considered by this research project.

DESIGN PROCESSES FOR SUBGRADE STABILIZATION

The following are different design processes for subgrade stabilization using stabilization geogrid or geotextiles.

ADOT Preliminary Engineering and Design Manual

The current ADOT MPEDM has no guidelines for the use of geogrid or geotextile for the purpose of subgrade stabilization.

Geosynthetic Design & Construction Guidelines Reference Manual (FHWA NHI-07-092)

This manual was developed for a class on the use of geosynthetics in highway applications (National Highway Institute 2008). The manual states that pavement failure may occur when the intrusion of subgrade soils into the granular base results in inadequate drainage and reduced stability. Therefore, a separation geotextile would generally be beneficial in a pavement section over the long term. The manual provides tables to help choose the appropriate construction survivability of a geotextile separation fabric.

Geogrid does not provide a separation function. If geogrid is used, the base course would have to perform as a filter, or a separation geotextile would have to be used with the geogrid.

In stabilization design, the geosynthetic (geotextile or geogrid) and the aggregate thickness required to stabilize the subgrade and provide an adequate roadbed or stable platform for construction are evaluated. For design of permanent roads, this stabilization lift also provides an improved roadbed. The base course thickness required to adequately carry the traffic loads over the design life of the permanent pavement may be reduced in light of the improved roadbed condition, provided an assessment is made of the improvement. No procedure for this assessment is provided in the NHI manual.

Various design guidelines for unpaved roadways or temporary roads are provided in the manual. Section 5.4 of the manual presents design guidelines for the use of geotextiles. The guidelines are based on *Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads* (Steward et al. 1977). Section 5.5 of the manual presents design guidelines for the use of geogrid. These guidelines are based on *Use of Geogrids in Pavement Construction* (USACE 2003), and *Design Method for Geogrid Reinforced Unpaved Roads. Parts I and II* (Giroud and Han 2004).

The guidelines in this reference manual would be useful in determining the required aggregate thickness and geosynthetic for subgrade stabilization during construction, but would not be useful for pavement section design.

Design Guidelines for Use of Geotextiles in Temporary and Unpaved Roads (Manual Section 5.4)

The design guidelines presented in Section 5.4 of the manual are based on the design procedure developed for the USFS (Steward et al. 1977).

Manual section 5.4, *Design Guidelines for Use of Geotextiles in Temporary and Unpaved Roads*, states: "Although the reinforcement function is inherently included in this method through improved bearing capacity, there is no direct reinforcing contribution (or input) for the strength characteristics of the geotextile." Most previous research has found that significant rutting (>4 inches) is required to obtain additional reinforcement benefit. However, this is beyond what is practically reasonable to achieve a stabilized platform for pavement section construction.

The design method presented in Section 5.4 was developed for unpaved roadways. Geotextiles may be used for subgrade stabilization for paved roads in the same manner as for unpaved roadways.

This unpaved roadway design procedure assumes 50 to 100 mm (2 to 4 inches) of rut, but less than 2 inches of rut is generally acceptable during construction of paved roads.The design procedure used the bearing capacity factors for less than 2 inches of rut. Once the stabilized lift is completed, construction proceeds, using standard methods and utilizing the recommended pavement design. Therefore, subgrade stabilization is for expedience in construction, to allow the use of construction equipment on a soft or saturated subgrade with a low CBR or R value. If the subgrade is hard, no stabilization is necessary. The cost-effectiveness is determined by the thickness of the base course needed to stabilize the subgrade prior to placing the base course for structural support necessary as part of the AASHTO pavement design. The thicker the base cost is, the greater the cost will be.

The design process for subgrade stabilization involves utilizing the geogrid or geotextile to reduce the required thickness of replacement ABC to stabilize the subgrade. The design process should allow less than 2 inches of rut at the top of the replacement ABC which would be the finished subgrade elevation. The design process does not address movement due to pumping at the top of the replacement ABC. For compaction of asphaltic concrete, pumping is more of a concern than rut depth, especially if the design ABC thickness for the pavement section is less than 12 inches.

It is possible that the subgrade may be moving slightly even after the subgrade stabilization since it is difficult to overcome a soft subgrade. However, this may be overcome by the additional aggregate base required as part of the pavement section, which is placed over the stabilization layer (geosynthetic and aggregate base). The biggest concern would be movement or pumping at the top of the aggregate base for the pavement section, just prior to placement of the asphalt. If movement is still occurring at the top of the aggregate base, then the stabilization has not been effective.

The step-by-step design procedure is as follows:

1. Determine the subgrade soil strength. This can be done in the field utilizing a field CBR test, cone penetrometer, or vane shear test. The subgrade shear strength c is measured in psi. Both the field CBR value and the cone penetrometer tests can easily be converted to subgrade shear strength c using the equations below. Subgrade shear strength, c, is directly measured by a portable field vane shear test.

   c in psi = 4 X CBR for the field CBR test (Eq. 5)

   c in psi = cone index divided by 10 or 11 (Eq. 6)
   for the Waterways Experiment Station (WES) cone penetrometer test
   (Dual Mass Dynamic Cone Penetrometer - ASTM D6951)

2. Make the strength determinations at several locations where the subgrade soils appear weakest. Strength should be evaluated over the depth ranges of 0 to 9 inches and 9 to 18 inches, taking six to 10 measurements at each location to obtain a good average value.

3. Determine the maximum single wheel load, maximum dual wheel load, and the maximum tandem wheel load during the design period, which for subgrade stabilization would be during the construction period. The manual offers these examples: a 10 yard dump truck with tandem axles has a dual wheel load of approximately 8,000 pounds; a motor grader has a wheel load in the range of 5,000 to 10,000 pounds.

4. Estimate the maximum amount of traffic anticipated for each design vehicle class.

5. Establish the amount of tolerable rutting during the design life, which would be for the construction platform to allow for proper placement of the pavement section. The design guidelines state that 2 to 3 inches of rutting is acceptable, but, in the opinion of the research team, less than 2 inches would appear to be more appropriate.

6. Obtain the appropriate subgrade stress level in terms of bearing capacity factors in accordance with Table 25.

Table 25. Subgrade Stress Determination

	Ruts (in.)	**Traffic (Passes of 18 kip axle equivalents)**	**Bearing Capacity Factor, N_C**
Without geotextile:	< 2	> 1000	2.8
	> 4	< 100	3.3
With geotextile:	< 2	> 1000	5.0
	> 4	< 100	6.0

The bearing capacity factor without geotextile should be 2.8 and with geotextile should be 5.0 to have less than 2 inches of rut.

7. Determine the required aggregate thickness from the USFS thickness design curves (Figures 2 and 3) modified for highway loadings for the maximum expected axle load. Enter the curves with the bearing capacity factor times the soil cohesion to evaluate the loading condition or stress level.

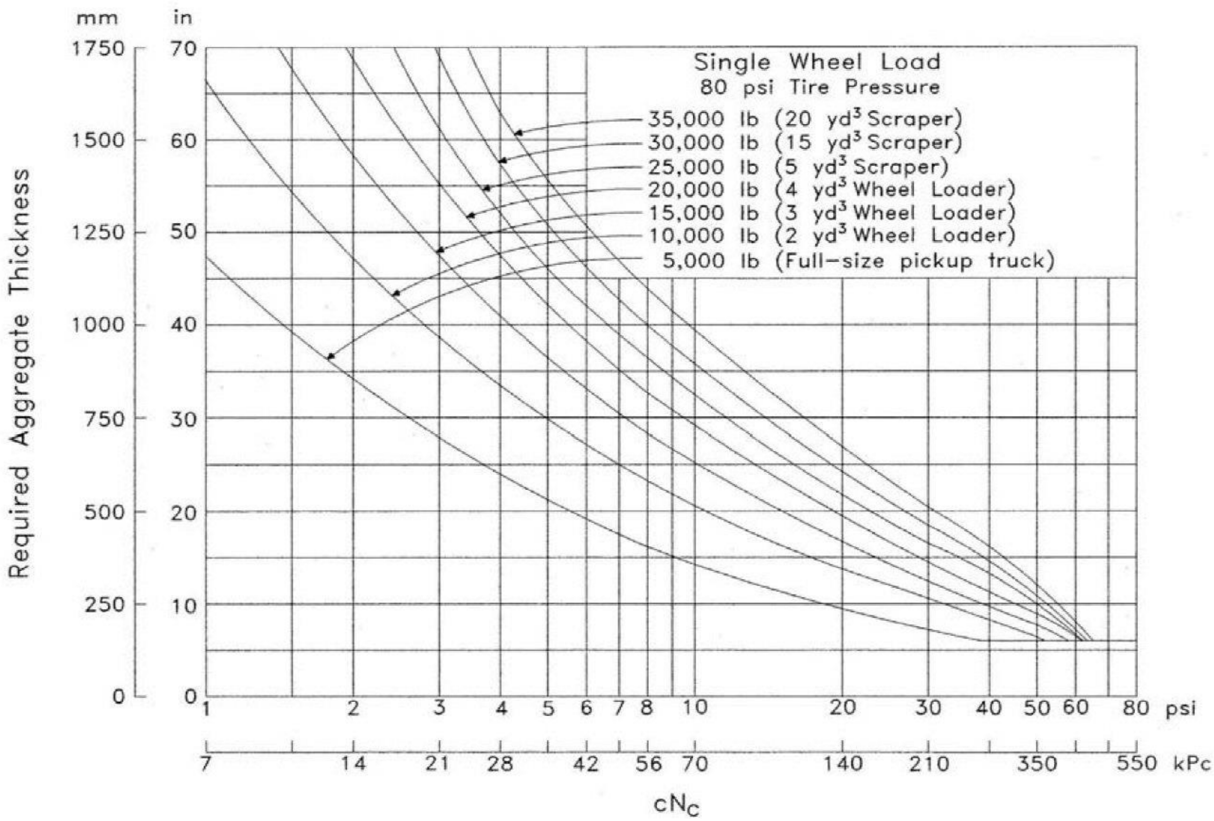

Figure 2. Aggregate Thickness – Single Wheel Load

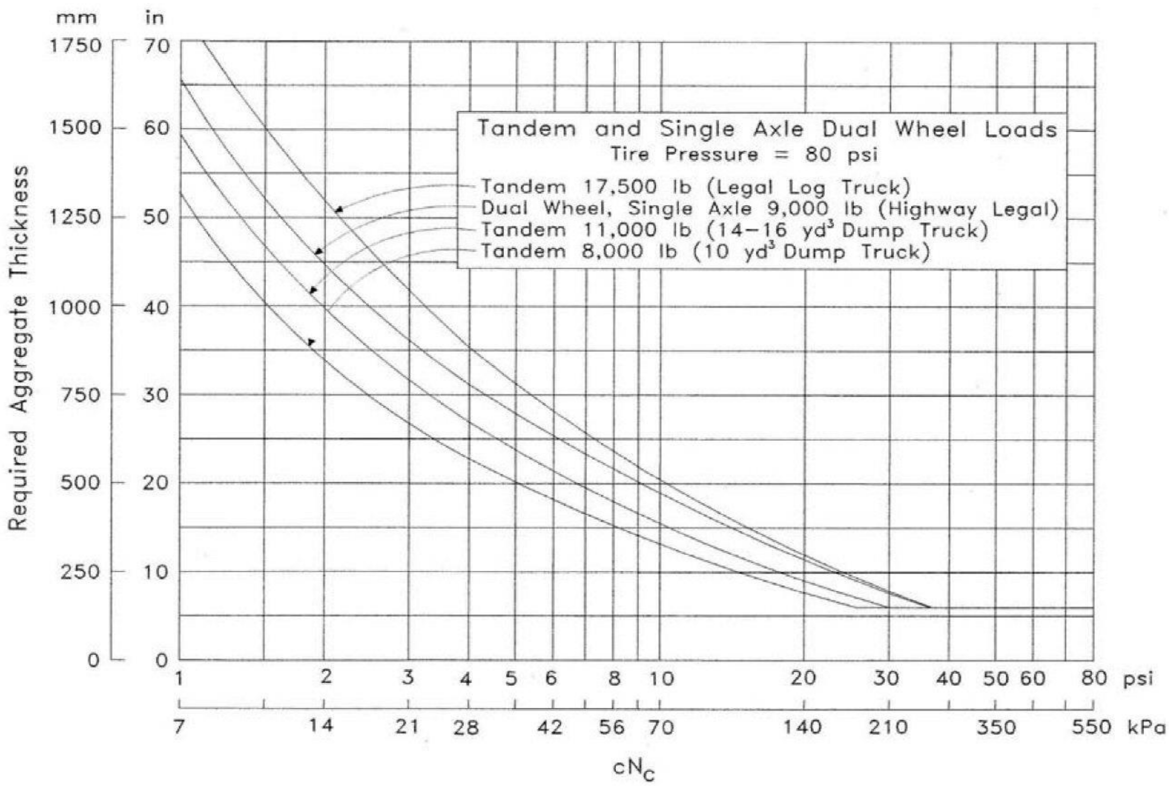

Figure 3. Aggregate Thickness – Tandem and Single Axle Dual Wheel Loads

8. Select the design thickness of ABC base course with and without geotextile. The design thickness should be given to the next higher 1 inch.

9. The geotextile stabilization fabric should conform to the drainage and filtration requirements of AASHTO M288 or, more specifically, conform to the AASHTO M288 requirement for separation with regard to AOS and permittivity based on the subgrade soil gradation.

10. Determine the geotextile survivability requirements.

11. Specify the geotextile property requirements.

12. Specify the construction requirements.

An example of the design process is presented in the manual. The ABC for stabilization without geotextile is determined using the lower bearing capacity factor of 2.8, and the required ABC for stabilization with the geotextile is then determined using the higher bearing capacity factor of 5.0; this reduces the required thickness of ABC. The cost savings from using the geotextile is due to the reduction in the stabilization ABC thickness.

The recommendation for geotextile fabric utilized for separation/stabilization is based on the construction survivability rating. Table 5-2 in the design guidelines shows the relationship between the soil CBR and aggregate or ABC thickness for equipment ground pressures less than 50 psi (350 kPa) and over 50 psi (350 kPa). For soils with a CBR of less than 1, at least 18 inches of aggregate must be placed over the geotextile for the higher contact pressure.

Table 5-3 in the manual shows geotextile property requirements, which are for stabilization applications (subgrade CBR < 3), and Geotextile Class 1 for high- survivability fabric. Table 5-4 in the manual shows geotextile property requirements, which are for separation applications (subgrade CBR > 3 and < 8), Geotextile Class 2, for moderate survivability fabric.

The permeability of the geotextile must exceed the permeability of the subgrade soil. The recommended AOS is based on the percent passing the No. 200 sieve for the subgrade soil (depending on whether more or less than 50 percent passes the No. 200 sieve).

The recommended ultraviolet stability of the geotextile should be 70 percent strength retained after 150 hours of UV exposure. These properties are called out in the current AASHTO M288 specification.

As a final note, stabilization geotextiles are recommended only when the CBR of the subgrade is less than 3. For a CBR greater than 3, geotextiles are rarely required for stabilization. However, they can provide some drainage and filtration in addition to the separation function.

Design Guidelines for Use of Geogrids in Temporary and Unpaved Roads (Manual Section 5.5)

Manual section 5.5, *Design Guidelines for Use of Geogrids in Temporary and Unpaved Roads*, states that the primary function of geogrid is to facilitate the construction and improve the performance of unpaved low-volume roads on weak subgrades; as for geotextiles below a permanent pavement section, the primary function in this application is reinforcement leading to a reduced amount of aggregate needed to provide a construction platform.

A secondary function of a geogrid is subgrade/base separation. Because of the large apertures or openings in the geogrids, the base course usually needs to provide the separation/filter function over subgrade soils with a high fines content. However, the geogrid prevents the base course from moving into the soft subgrade soils as long as the size of the openings in the geogrid is > D_{50} and < $2D_{85}$ of the aggregate base above the geogrid. The D_{85} size of the aggregate above the geogrid must be less than 5 times the D_{85} of the subgrade soil below the geogrid, or a separation fabric must be used with the geogrid. This would likely be the case for fine-grained subgrade soils.

USFS Design Method (Steward et al. 1977) Modified by USACE (2003).

The first design method presented for geogrids is an empirical design method (Steward et al. 1977). Full-scale experiments were utilized and reported on in 2003 by the USACE to evaluate the applicability of the previously presented design procedure for geotextile. The analysis concluded that the bearing capacity of 2.8 for unreinforced roads was acceptable in the subgrade stabilization design process. However, for stabilization with geogrid, a bearing capacity factor of 5.8 was recommended. This is higher than the previously recommended bearing capacity factor of 5.0 for geotextile. The reduction of aggregate for stabilization would be determined in the same manner as the reduction for the geotextile, just using the higher bearing-capacity factor. It is recommended that a geotextile be used as a separator beneath the geogrid unless the aggregate can act as a separator for the subgrade as previously defined.

Giroud and Han Design Method (2004).

The second design method presented for geogrids is the empirical design method of Giroud and Han (2004). Giroud and Han developed a theoretically based and empirically calibrated design method specifically designed for geogrid-reinforced unpaved roads and areas. The Giroud-Han method takes into account the distribution of stresses, strength of the base course material, geogrid-aggregate interlock, and geogrid in plane stiffness in addition to factors considered in the previous design procedures such as traffic, wheel load, tire pressure, subgrade strength, rut depth, and influence of reinforcing geosynthetics. The properties of the base course are considered in the design process, which is viewed as an improvement on the previous design processes. All of these factors are entered into an empirical design equation for the required thickness of base course; the document also provides a design example that shows how the equation is utilized.

The limitations of the Giroud-Han method are as follows:

- The subgrade soil is assumed to be saturated and exhibits undrained shear behavior under traffic loading.
- The subgrade soil modulus is based on a correlation between the field CBR and field resilient modulus for fine-grained soils.
- The method is applicable to a rut depth in the range of 2 to 4 inches, field subgrade CBR less than 5, maximum ratio of base course modulus to subgrade modulus of 5, and maximum number of passes of 10,000 ESALS.
- The tension membrane effect was not taken into account, so the expected rut is limited to 4 inches.
- The influence of geogrid reinforcement is considered through a bearing capacity factor of 5.71 and the effect of the aperture stability modulus.
- For geotextile, the bearing capacity factor is reduced to 5.14 with an aperture stability modulus of 0 since there are no aggregate size apertures in geotextiles.
- With no geosynthetic reinforcement, a bearing capacity factor of 3.14 is applicable.
- A minimum base course thickness of 4 inches is required.

The manual states that these limitations may change as additional empirical data becomes available. (FHWA 2008, pp. 5-27–5-29)

The step by step design procedure is as follows:

1. Determine the subgrade soil strength. This can be done in the field utilizing a field CBR test, cone penetrometer, or vane shear test. The subgrade shear strength c in psi = 4 X CBR for the field CBR test, c in psi = cone index divided by 10 or 11 for the Waterways Experiment Station (WES) cone penetrometer test (Dual Mass Dynamic Cone Penetrometer - ASTM D6951), and c is directly measured by a portable field vane shear test.

2. Make the strength determinations at several locations where the subgrade soils appear weakest. Strength should be evaluated over the depth range of 0 to 9 inches and 9 to 18 inches, making six to 10 measurements at each location to obtain a good average value.

3. Determine the maximum single wheel load, maximum dual wheel load, and the maximum tandem wheel load during the design period, which for subgrade stabilization would be during the construction period. For example, a 10-yard dump truck with tandem axles has a dual wheel load of approximately 8,000 pounds, and a motor grader has a wheel load in the range of 5,000 to 10,000 pounds.

4. Make preliminary calculations, such as selecting the allowable rut depth and calculating the radius of the equivalent rut depth.

5. Check the capacity of the subgrade soil to support the wheel load without reinforcement. If the subgrade soil cannot support the wheel load, reinforcement is required.

6. The required base course thickness should be determined using Equation 7. The calculation of the base course may require iteration. The minimum base course thickness is 4 inches.

$$h = \frac{0.868 + (0.661 - 1.006 J^2)\left(\frac{r}{h}\right)^{1.5} \log N}{\left[1 + 0.204\left(R_E - 1\right)\right]} \left(\sqrt{\frac{\frac{P}{\pi r^2}}{\frac{s}{f_s}\left[1 - 0.9 e^{-\left\{\frac{r}{h}\right\}^2}\right] N_c f_c CBR_{sg}}} - 1 \right) r \qquad \text{(Eq. 7)}$$

Where:

$(0.661\text{-}1.006\ J^2) > 0$

h	=	required base course thickness (in. or m)
J	=	aperture stability modulus in metric units (N-m/degree)
P	=	wheel load (lb or kN)
r	=	radius of tire print (in. or m)
N	=	number of axle passes
R_E	=	modulus ratio = $E_{bc}/E_{sg} = 3.28\ CBR_{bc}^{0.3} / CBR_{sg} \leq 5$
E_{bc}	=	base course resilient modulus (psi or MPa)
E_{sg}	=	subgrade soil resilient modulus (psi or MPa)
CBR_{bc}	=	aggregate CBR
CBR_{sg}	=	subgrade CBR
f_s	=	rut depth factor
s	=	maximum rut depth (in. or m)
N_c	=	bearing capacity factor
	=	3.14 for unreinforced roads
	=	5.14 for geotextile reinforced roads
	=	5.71 for geogrid reinforced roads
f_c	=	factor relating subgrade CBR to undrained cohesion, c_u = 4.3 psi (30 kPa)

7. After calculation, select the base course thickness.

8. Determine whether a subgrade separation fabric is required, using the method discussed previously.

9 and 10. Specify the geogrid properties. If the aperture stability modulus was a factor utilized in the design equation, it must be determined for the geogrid. Otherwise, the aperture stability modulus must be assumed to be 0. Other properties for geogrid are presented in Table 5-5 of the manual, *Geogrid Survivability Property Requirements for Stabilization and Base Reinforcement Applications.* None of the properties in that table have any impact on the base

course requirement for geogrid in the Giroud-Han design method since they are not factors in the Giroud-Han equation.

11. Specify the construction requirements.

Examples of the modified Giroud-Han method show calculations for required base course thicknesses for unreinforced unpaved road and unpaved road with a stiff biaxial grid. Another example shows the results of a similar analysis using the method from Section 5.4, but modified to include geogrid. The bearing capacity factor used for geogrid is 5.8; the bearing capacity factor used for unreinforced unpaved roads is 2.8.

The results from the two methods (Giroud-Han and modified Section 5.4) for the geogrid design example were essentially the same. This may not always be the case.

Geotextiles and Geogrid in Permanent Paved Roadways

The remainder of Chapter 5 in the manual is devoted to design guidelines for use of geotextiles and geogrid in permanent paved roadways.

Section 5.6 presents design guidelines for use of geotextiles in permanent paved roadways. Subsection 5.6-1 discusses the requirements for separation, which are presented in AASHTO M288. The geotextile design process in subsection 5.6-2 for stabilization assumes a rut of less than 2 inches and describes the same procedure as in Section 5.4 for unpaved and temporary roads. For CBR less than 3, no benefit is provided in the pavement section, and additional aggregate is deemed necessary to provide a stable construction platform. Subsection 5.6-3 shows a design example for permanent roadway subgrade stabilization that goes through the same steps shown in Section 5.4. The additional aggregate is deemed necessary to prevent pumping and subgrade intrusion into the aggregate base.

Geotechnical Aspects of Pavements Reference Manual (FHWA NHI-05-037)

This manual was developed for a class on geotechnical aspects of pavements (National Highway Institute 2006). Subgrade improvement and strengthening is described in Section 7.6. Subsection 7.6.2, *Characteristics of Stabilized Soils*, states that:

> Although mechanical stabilization with thick granular layers or geosynthetics and aggregate subbase provides the potential for strength improvement of the subgrade over time, this is generally not considered in the design of the pavement section, and no increase in structural support is attributed to the geosynthetic. However, the increase in gravel thickness (minus an allowance for rutting) can contribute to the support of the pavement. Alternatively, the aggregate thickness used in conjunction with the geosynthetic is designed to provide an equivalent subgrade modulus, which can be considered in the pavement design, discounting the additional aggregate thickness of the stabilization layer. Geosynthetics also allow more open

graded aggregate, thus providing for the potential to drain the subbase into edge drains and improving its support value.

Subsection 7.6.4, *Geotextiles and Geogrids*, presents the following design process for subgrade stabilization.

The design of the geosynthetic for stabilization is completed using the design-by-function approach in conjunction with AASHTO M288, in the steps from FHWA HI-95-038 outlined below. A key feature of this method is the assumption that the structural pavement design is not modified at all in the procedure. The pavement design proceeds exactly according to standard procedures, as if the geosynthetic was not present. The geosynthetic instead replaces additional unbound material that might be placed to support construction operations, and does not replace any part of the pavement section itself. However, this unbound layer will provide some additional support. If the soil has a CBR of less than 3, and the aggregate thickness is determined based on a low rutting criteria in the following steps, the support for the composite system is theoretically equivalent to a CBR = 3 (resilient modulus of 30 MPa (4500 psi)). As with thick aggregate fill used for stabilization, the support value should be confirmed though field testing using, for example, a plate load test or FWD test to verify that a minimum composite subgrade modulus has been achieved. Note that the FHWA procedure is controlled by soil CBR, as measured using ASTM C4429.

1. Identify properties of the subgrade, including CBR, location of groundwater table, AASHTO and/or USCS classification, and sensitivity.
2. Compare these properties to those in Table 7-15, or with local policies. Determine if a geosynthetic will be required.
3. Design the pavement without consideration of a geosynthetic, using normal pavement structural design procedures.
4. Determine the need for additional imported aggregate to ameliorate mixing at the base/subgrade interface. If such aggregate is required, determine its thickness, t1, and reduce the thickness by 50 percent, considering the use of a geosynthetic.
5. Determine additional aggregate thickness t2 needed for establishment of a construction platform. The FHWA procedure requires the use of curves for aggregate thickness vs. the expected single tire pressure and the subgrade bearing capacity, as shown in Figure 7-21, modified for highway applications. For the purposes of this manual, the curves have been correlated with common pavement construction traffic. Select N_C based on allowable subgrade ruts, where:
   N_C = 5 for a low rut criteria (< 50 mm (< 2 in.)),
   N_C = 5.5 for moderate rutting (50 – 100 mm (2 – 4 in.)), and
   N_C = 6 for large rutting (> 100 mm (> 4 in.)).
   (For comparison without a geotextile: N_C = 2.8, 3.0, or 3.3 respectively for low to large ruts.)
   Alternatively, local policies or charts may be used.

6. Select the greater of t2 or 50% t1.
7. Check filtration criteria for the geotextile to be used. For geogrids, check the aggregate for filtration compatibility with the subgrade (see Section 7.2), or use a geotextile in combination with the grid meeting the following criteria. The important measures include the AOS, the permeability (k), and permittivity (ψ) of the geotextile, and the 95 percent opening size, defined as the diameter of glass beads for which 95 percent will be retained on the geosynthetic. These values will be compared to a minimum standard or to the soil properties as follows

    - AOS ≤ D85 (Wovens)
    - AOS ≤ 1.8 D85 (Nonwovens)
    - kgeotextile ≥ ksoil
    - ψ ≥ 0.1 sec-1
8. Determine geotextile survival criteria. The design is based on the assumption that the geosynthetic cannot function unless it survives the construction process. The AASHTO M288-99 standard categorizes the requirements for the geosynthetic based on the survival class. The requirements for the standard include the strength (grab, seam, tear, puncture, and burst), permittivity, apparent opening size, and resistance to UV degradation, based on the survival class. The survival class is determined from Table 7-5 (Section 7.2.12). For stabilization of soils, the default is Class 1, and for separation, the default is Class 2. These requirements may be reduced based on conditions and experience, as detailed in AASHTO M288. For geogrid survivability, see AASHTO standard PP 46-01, *Recommended Practice for Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures* (2005) and Berg et al. (2000).

The manual generally follows the original procedure set forth in 1995 based on the USFS design method (Steward et al. 1977).

Caltrans Subgrade Enhancement Geosynthetic Design and Construction Guide

This guide was prepared by Caltrans to assist pavement design engineers in the selection of an appropriate Subgrade Enhancement Geosynthetic (SEG) including Geotextile (SEG_T) and Geogrid (SEG_G) (Caltrans 2013).

SEG is a geotextile or geogrid placed between the pavement structure and the subgrade (the subgrade is usually untreated). The placement of the SEG below the pavement structure provides subgrade enhancement by bridging soft areas in the subgrade.

A Subgrade Enhancement Geotextile (SEG_T) is utilized primarily for filtration and separation of a soft subgrade and the subbase or base materials of the pavement section. The separation function prevents the subbase or base aggregate and the subgrade from mixing. It can also reduce pore water pressure in the subgrade soil through a mechanism of filtration and drainage. Secondary benefits of a subgrade enhancement geotextile are lateral restraint and reinforcement. However, reinforcement requires deformation of the subgrade to engage the tensile strength in the geotextile.

A Subgrade Enhancement Geogrid (SEG_G) is utilized primarily for stabilization of the subgrade through lateral restraint of the subbase or base materials through a process of interlocking the aggregate and the apertures of the geogrid. The level of lateral restraint that is achieved is a function of the type of geogrid and the quality and gradation of the base or subbase material placed over the geogrid. The particle size of the base or subbase material should be appropriate for the aperture size of the geogrid. If the aperture size is correct, the overlying aggregate in the base or subbase material is restrained from punching into and mixing with the soft subgrade soils below the geogrid. Very little deformation of the geogrid is needed to achieve the lateral restraint and confinement. Separation and filtration/vertical drainage are secondary functions of a geogrid.

According to Caltrans, SEG benefits include:

- Prevention of premature pavement failure.
- Reduction of long-term maintenance costs.
- Reduction of subbase or aggregate base thickness in some situations.
- Reduction or elimination of soft subgrade removal.
- Increased performance life and reliability for the pavement.
- Prevention of contaminated subbase or base.
- Better performance of a pavement over soils subject to freeze/thaw.
- Reduced disturbance of soft or sensitive subgrade during construction.
- Ability to install during a wide range of weather conditions.

The appropriate applications for the use of an SEG are for poor or low strength soils with a CBR of less than 3 or R-Value less than 20.

An SEG_G is most applicable for R-Values of less than 25 or CBR less than 3.5 (Resilient Modulus less than 5000 psi).

An SEG_T is most applicable for R-Values of less than 20 or CBR less than 3 (Resilient Modulus less than 4500 psi).

On very soft subgrades, R-Values less than 10 or CBR less than 2 (Resilient Modulus less than 3000 psi), it may be necessary to place a thicker initial lift (minimum of 6 inches) of subbase or aggregate base on top of the SEG to effectively bridge the soft subgrade soils and avoid bearing capacity failure under construction traffic loading.

These correlations for R-Value, CBR, and Resilient Modulus are taken directly from the Caltrans design guidelines. See Appendix P for more information about correlating R-Value, CBR, and Resilient Modulus.

Use of a geogrid is not recommended unless the subbase or aggregate base material meets the natural filter criteria as follows:

- D_{15} Base/D_{85} Subgrade ≤ 5 and D_{50} Base/D_{50} Subgrade ≤ 25

- D_{15}, D_{85}, and D_{50} are grain sizes of the soil particles for which 15 percent, 85 percent, and 50 percent, respectively, of these materials (base or subgrade) is smaller than these sieve sizes.

If the subbase or aggregate material does not meet the above natural filter requirements, then geotextiles that meet both separation and stabilization requirements are recommended.

A subgrade enhancement geotextile or geogrid should not be utilized if the R-Value for the subgrade soil exceeds 40.

A flow chart is provided to help make the correct choice in the design process. The potential economic and intrinsic benefits should also be investigated.

Caltrans identifies five possible choices of subgrade enhancement geotextiles: Caltrans Classes A1, A2, B1, B2, and B3. There is only one choice of subgrade enhancement geogrid. Class A1 is woven, and Class A2 is nonwoven; these are primarily separation geotextiles of moderate strength for use in separation applications. Class B1 and B2 geotextiles are woven geotextiles of high strength. Class B3 geotextile is a nonwoven geotextile of high strength. The Class B1, B2, and B3 geotextiles are used for separation and stabilization or reinforcement. A geogrid specification is also presented in the design guidelines.

The guide provides the following guidelines:

- The possibility of stabilizing soft material with lime for clay soils with a PI greater than 12 is considered.
- A filter analysis must also be performed on the subgrade and base course to determine whether the filtration criteria are met by the base course for a geogrid application. For applications involving drainage and filtration for geotextiles, the design engineer must verify that the permeability of the geotextile is greater than the permeability of the subgrade soil.
- Recycled concrete should not be used in conjunction with a polyester geotextile fabric.
- A subgrade enhancement geotextile is not necessary if the subgrade is planned for chemical stabilization (such as with lime or cement).
- If a subgrade enhancement geotextile is utilized, an R-Value of less than 20 may be increased to a design R-Value of 20 in the pavement design.

- If a subgrade enhancement geogrid is utilized, an R-Value of less than 25 may be increased to a design R-Value of 25 in the pavement design. An additional geotextile separator must be used if the base course does not conform to the natural filter criteria.

Construction considerations are also provided for subgrade enhancement with geotextiles and geogrids.

Use of Geogrids in Pavement Construction (ETL 1110-1-189)

This technical letter provides guidance, basic criteria, and information for the use of geogrids in the design and construction of aggregate-surface roads, which would be similar to a construction platform for permanent pavement construction (USACE 2003).

Geogrids in aggregate-surface roads can be used to support two pavement applications: mechanical subgrade stabilization and aggregate base reinforcement. The application is predetermined by the subgrade soil strength. The type of geosynthetic recommended for use in aggregate-surface roads is based on the subgrade soils conditions. Geosynthetics used to construct pavements over very soft subgrade conditions typically serve to mechanically stabilize the subgrade. As the design subgrade strength increases, the primary application of the geosynthetic transitions from mechanical subgrade stabilization to reinforcement.

The technical letter states that the first step in the design process is to determine the properties of the subgrade including the grain size distribution, Atterberg limits, and in-situ shear strength or bearing capacity. The in-situ shear strength can be measured directly using vane shear devices, or indirectly using bearing capacity correlations from the CBR or dynamic cone penetrometer (DCP) test. The design subgrade strength is defined as the 75th percentile strength of the top 18 inches of the subgrade. The 75th percentile strength is the value at which 75 percent of the recorded soil strength readings are higher than this value.

A figure is provided to show the correlation between the values for DCP (mm/blow), CBR (%), and Shear Strength c (psi).

For subgrade with a CBR less than or equal to 0.5, the primary application is mechanical subgrade stabilization. A nonwoven geotextile is recommended for separation, and a biaxial geogrid is recommended for aggregate reinforcementThe geogrid and geotextile are used together to build a construction platform in accordance with the design requirements for an aggregate surfaced roadway. No reduction of aggregate base course is recommended. At these low material strengths, the full depth of the aggregate fill should be used, and no reduction of aggregate thickness is recommended, even when using a geogrid; thus, the unreinforced thickness design should be used. The nonwoven geotextile should be placed directly on the subgrade, followed by the geogrid and then the aggregate fill. The designed construction platform serves to bridge over the very soft subgrade soil, becomes an aid in obtaining compaction densities, and enhances construction expediency.

For subgrade with a CBR in the range of 0.5 to 2.0, both subgrade stabilization and base reinforcement applications are mobilized. The document recommends a nonwoven geotextile for separation. A geogrid for reinforcement may also be cost-effective. For this subgrade strength level, both a geotextile and geogrid are recommended, and the aggregate thickness for subgrade stabilization can be reduced using the appropriate reinforced bearing capacity factor in the design procedure.

The document recommends the use of a nonwoven geotextile for separation for fine-grained subgrades with a CBR in the range of 2.0 to 4.0. A nonwoven geotextile is also recommended for separation when the designer has experienced separation problems with the construction materials during construction. Insufficient data are available for aggregate-surface roads at these subgrade strengths to accurately define an appropriate bearing capacity factor. Thus, the document recommends that the designer use a bearing capacity factor for the inclusion of both a geotextile and geogrid provided in the design procedure. This recommendation is based on the assumption that the geotextile serves to separate the different pavement materials and provides little reinforcement benefit.

For subgrade with a CBR above 4.0, research has indicated significant reinforcement at these subgrade strength values, but the benefits have not been quantified conclusively. The primary geogrid application at these subgrade strength values is base reinforcement. Geogrids can be used as a construction expedient to solve site-specific construction problems and localized soft soil zones.

As stated previously, the first step of the design procedure is to determine the subgrade strength. Once the design subgrade conditions have been determined, the applicability of geosynthetics should be assessed using the previously discussed criteria. The document suggests that the following procedure can be used to design the aggregate-surface road or construction platform, and that otherwise the procedures in Technical Manual TM 5-822-12 should be used (US Department of the Army 1995). If the use of a geotextile and/or geogrid is warranted, the subgrade soil strength must be converted from CBR to shear strength (c) if this has not already been done.

The next step is to determine the design traffic, which for a construction platform is typically construction equipment. Table 4 of the document lists design wheel loads for various military vehicle designations.

The design aggregate thickness presented in this procedure is based upon the development of a maximum 2-inch rut after 1000 passes of an 18-kip equivalent axle load.

The next step presented in the document is to determine the bearing capacity factor (N_C). Both the reinforced and unreinforced bearing capacity factors were determined using empirical data from full-scale Engineer Research and Development Center test sections. The unreinforced bearing capacity factor is 2.8. The reinforced bearing capacity factor for a geotextile alone is 5.0, based on Technical Manual TM 5-818-8, *Engineering Use of Geotextiles* (US Department of the Army, US Department of the Air Force 1995). However, recent research has shown that this factor should be reduced to 3.6 for conservative designs. The bearing capacity for the use of a geotextile separator and geogrid reinforcement together is 5.8. Insufficient data exist to determine a bearing capacity factor for geogrid alone. In the absence of sufficient data, a bearing capacity factor of 5.8 is recommended, based upon engineering judgment from observations of geotextile and geogrid reinforced pavement sections. This assumes that the geotextile serves as a separation fabric with little reinforcement benefit. Bearing capacity factor recommendations are summarized in Table 26.

Table 26. Bearing Capacity Factors from Technical Letter TL 1110-1-189

<table>
<tr><th colspan="8">Reinforced Bearing Capacity Factors, N_C[1], for Aggregate-Surfaced Pavements</th></tr>
<tr><th colspan="8">Step 1: Determine Design Subgrade Soil Strength and Geosynthetic Applicability</th></tr>
<tr><th>CBR ≤ 0.5</th><th colspan="3">0.5 < CBR ≤ 2.0</th><th colspan="3">2.0 < CBR ≤ 4.0</th><th>CBR > 4.0</th></tr>
<tr><td rowspan="2">Use a geotextile and a geogrid at subgrade-base interface. No aggregate thickness reduction is recommended. Use TM 5-822-12 for thickness design.</td><td colspan="3">Both a geogrid and a geotextile are recommended. Use this design procedure for aggregate thickness reduction.</td><td colspan="3">A geotextile is required for fine-grained subgrades. A geogrid may also be cost-effective. Perform a life-cycle cost analysis.</td><td rowspan="2">Perform a cost analysis. Consider "hidden" benefits. Inadequate data are available to determine bearing.</td></tr>
<tr><td>Geotextile
5.0[3]</td><td>Geogrid
5.8</td><td>Both[2]
5.8</td><td>Geotextile
5.0[3]</td><td>Geogrid
5.8</td><td>Both
5.8</td></tr>
<tr><td colspan="8">[1] The unreinforced bearing capacity factor, N_C, is 2.8.
[2] Both a geotextile and a geogrid are recommended. The geotextile serves primarily as a separation fabric.
[3] Use a factor of 3.6 for conservative geotextile-reinforced pavement designs.</td></tr>
</table>

The document then states that the required aggregate thickness should be determined using Figures 5 through 7 of the referenced document for single-wheel, dual-wheel, and tandem-wheel gear loads. The subgrade bearing capacity is determined by multiplying the subgrade strength (C) in psi by the appropriate bearing capacity factor. The required aggregate thickness should be rounded up to the next-higher inch. The required aggregate thickness for the unreinforced condition should be determined using a bearing capacity factor of 2.8. The reinforced design should then be determined depending upon the type of reinforcement utilized.

The document also recommends minimum geotextile and geogrid material property requirements. These are shown in Tables 27 and 28.

Table 27. Minimum Geotextile Specifications from Technical Letter TL 1110-1-189

Minimum Geotextile Specification Requirements[1]		
Geotextile Property	**ASTM Test Method**	**Minimum Requirement**[2]
Grab Strength (lb)	D 4632	200
Puncture Strength (lb)	D 4833	80
Burst Strength (psi)	D 3786	250
Trapezoid Tear (lb)	D 4533	80
Apparent Opening Size (mm)	D 4751	< 0.43
Permittivity (sec^{-1})	D 4491	0.05
Ultraviolet Degradation (% Retained Strength @ 500 hr)	D 4355	50
Polymer Type	--	Polyester (PET) or Polypropylene (PP)

[1] This specification is for nonwoven geotextiles, which are recommended for typical separation applications.
[2] Minimum requirements include both machine and cross-machine directions.

Table 28. Minimum Biaxial Geogrid Specifications from Technical Letter TL 1110-1-189

Minimum Biaxial Geogrid Specification Requirements		
Geogrid Property	**ASTM Test Method**	**Minimum Requirement**[1]
Mass per Unit Area (oz/yd^2)	D 5261	9.0
Aperture Size – Machine Direction (in.)	Direct Measure	1.0
Aperture Size – Cross-Machine Direction (in.)	Direct Measure	1.3
Wide-Width Strip Tensile Strength (lb/ft)%: Strength at 5% Strain – Machine Direction Strength at 5% Strain – Cross-Machine Direction Ultimate Strength – Machine Direction Ultimate Strength – Cross-Machine Direction	D 6637	 700 1,200 1,200 2,096
Manufacturing Process	--	Punched and Drawn

[1] This specification is for nonwoven geotextiles, which are recommended for typical separation applications.
[2] Minimum requirements include both machine and cross-machine directions based on Webster (1993).

These recommended material properties may be compared to AASHTO M288 for the geotextiles. In addition, only nonwoven geotextiles are recommended, which may be the reason geotextiles are not recommended for reinforcement. (Woven geotextiles may be more effective in reinforcement applications.)

ARMY TM 5-818-8, AIR FORCE AFJMAN 32-1030 Technical Manual (US Department of the Army and US Department of the Air Force 1995)

Chapter 2, *Geotextiles in Pavement Applications*, discusses the use of geotextiles in pavement. Section 2-4, *Separation and Reinforcement*, and more specifically, Section 2-7, *Design for Reinforcement*, present the design procedure for reinforcement of gravel surface roads. The design procedure is essentially the same as that presented in NHI Course No. 132013, FHWA NHI-07-092 (FHWA 2008) - *Geosynthetic Design & Construction Guidelines*, which was previously discussed. The thickness design curves are different in that there are three sets of design curves for single-, dual-, and tandem-axle wheel loads. Radius of contact areas are shown for the dual-axle and tandem-axle loads.

Stabilization Selection Guide for Aggregate and Native-Surfaced Low Volume Roads (Kestler 2009)

This manual outlines various subgrade stabilization options, both chemical and mechanical, for soil stabilization. The chemical options include traditional and nontraditional chemical additives. The mechanical options involve improvement of the subgrade by increasing the density by compaction or, if compaction is not an option, by the use of cellular confinement, fiber reinforcement, or geotextile/geogrid reinforcement. The mechanical stabilization option generally emphasizes use for localized sections and is not typically recommended as a stabilization technique for a road of any length. The mechanical stabilization technique refers to Maher et al. (2005) in an appendix to the report.

For geosynthetics, the report references three primary empirical design methods: Barenberg et al. (1975), Giroud and Noiray (1981), and Steward et al. (1977). Reference is also made to a cost analysis prepared by Tingle and Jersey (2007) with cost comparisons for ABC thickness and costs for the different methods at different CBR strengths.

The first design method was provided by Barenberg et al. (1975), modified by Steward et al. (1977), and adopted by the Forest Service and the USACE. The method was further modified by Tingle and Webster (2003) to include the geogrid design, as described in *Engineering Technical Bulletin 1110-1-189* (USACE 2003).

An alternative design method is the design theory presented by Giroud and Noiray (1981). The Giroud and Noiray design theory was further modified by Giroud and Han (2004) to include stress distribution, base-course strength properties, geosynthetic base interlock, and geosynthetic in-place stiffness.

The recommended design procedure is presented in Appendix I of the manual, but reference is also made to Appendix H, *Geotextile/Geogrid Reinforcement*. For low-volume unpaved road design, geotextile and/or geogrid reinforcement is taken into consideration by increasing the equivalent bearing capacity factor of the underlying subgrade soil. For soft subgrade soils, the bearing capacity factor, NC, for unreinforced, unpaved roads is 2.8, while the NC for geotextile-reinforced roads is 4.2, and the NC for geogrid and geotextile-reinforced soils is 6.7. Some state DOTs do not include separation as a structural design consideration, but consider separation only to prevent aggregate/subgrade mixing. The roadway should still be designed with adequate base and/or subgrade support, taking into account the improved strength from the geosynthetic product.

Geogrids and geotextiles are most effective when used within thin aggregate layers. As the base layer thickness increases, the stresses and strains near the bottom of the base layer decrease, and the influence of the lateral base course restraint also decreases. In addition, the mechanisms causing base/subgrade intermixing are reduced as the aggregate base thickness increases.

The design method developed by Steward, Williamson, and Mohney (1977) is presented in Appendix I of the manual. This design method is essentially the same method previously presented in NHI Course No. 132013, FHWA NHI-07-092 (August 2008) - *Geosynthetic Design & Construction Guidelines*. However, the design charts show truck axle loads in kilo-Newton (kN) instead of English units.

Research at Oxford on Reinforced Unpaved Roads (Houlsby and Jewell 1990)

This research presents a new method for the design of unreinforced and reinforced unpaved roads. However, this method is not in any design process currently utilized by the federal government. This design method is based on the concept that, as vertical loads are applied to a granular layer, horizontal stresses must also develop within that layer. These stresses are held in equilibrium by shear stresses at the surface of the subgrade, and in unreinforced roads, these shear stresses have a detrimental effect on the bearing capacity. The new method moves away from a previous emphasis on membrane action to explain the function of reinforcement, and is therefore able to account for observed improvements due to reinforcement at small surface deflections (small rut depths).

The principal drawback of the previous design methods is that the contribution of the tensioned membrane is usually very small except at large (often unacceptable) rut depths. Model studies and finite element analyses were conducted at Oxford University to research this problem. The results of this work lead to new understanding of reinforced unpaved roads that places less emphasis on the importance of a tensioned membrane.

When a vertical load is applied at the surface of the granular fill layer, it causes high horizontal stresses, as well as vertical stresses, under the loaded area. The resulting horizontal thrust in the soil is partly resisted by horizontal stress in the fill outside the loaded area, but it also results in outward shear stresses on the surface of the subgrade soil below the granular fill area. The presence of such outward shear stresses reduces the appropriate bearing capacity factor for the subgrade soil, possibly to as little as half of the value for purely vertical loading directly on the subgrade soil. If reinforcement is introduced, these shear stresses are picked up by the reinforcement, which is put into tension, and purely vertical forces are transmitted to the subgrade below, allowing the full bearing capacity of the clay to be mobilized.

This description helps explain why reinforcement is able to provide an improvement in road performance even at very small rut depths, since it does not depend on the concept of a curved tensioned membrane. In this case, geosynthetics with a high modulus, i.e., with high strengths at 2 percent and 5 percent strains and high stiffness, are most important.

For a typical foundation design, it is assumed that the load spreads out or expands beneath the foundation at a 30 degree angle directly below the load; therefore, the load has less effect at greater depths. For granular backfill, it was found that load spreads out at a broader 45 degree or 50 degree angle. The higher the friction angle for the granular fill, the greater the angle, or the more the load will spread out. For this reason, reinforcement with a geosynthetic works better when the thickness of the granular fill is smaller.

With these basic concepts, design charts were created with inputs of wheel load, radius of the wheel load, subgrade soil strength, angle of friction for the granular fill, and unit weight of the granular fill. These are incorporated into design curves to determine the thickness of granular fill required for unreinforced and reinforced conditions, as well as the required tensile strength for the geosynthetic. The allowable strain in the geosynthetic at this tensile strength to achieve a small rut should be 3 percent.

Charts are presented for granular fill friction angle values of 30, 35, 40, and 45 degrees. The design charts are also presented for three values of load spreading angles of 25, 35, and 45 degrees, resulting in a total of 12 design charts (4x3). A design example shows how the charts are used with metric units.

Although this design method is presented, it has not been evaluated and is not being utilized or recommended by FHWA or other federal government entities such as the USFS or US Army Corps of Engineers. However, due to its basis on a low rut depth, it should be considered in the future as a possible design alternative.

SUMMARY OF DESIGN PROCESSES

Several design processes for subgrade stabilization were reviewed in this chapter. FHWA and USACE both have design processes that are based on the design guidelines developed for the USFS by Steward et al. (1977). FHWA also uses the empirical design equation developed by Giroud and Han (2004). Caltrans has also developed a design process for subgrade stabilization using geotextiles and geogrid.

The design method developed for the USFS has been utilized by FHWA as well as the USACE and the US Army and Air Force. The method has been modified over the years based on field experience and testing to account for different types of geotextiles and geogrid. This design method is based on soil properties that can be easily measured in the field using standard test methods and design charts for different vehicle types. This design method can be used for geotextiles and for geogrid.

The design method developed by Giroud and Han (2004) utilizes an equation with several variables. One of the variables is the geogrid property aperture stability. There are currently no standard test methods for aperture stability. Further, it is not known whether aperture stability is a critical property for all types of geogrid or just for the geogrid that was used to calibrate the equation. The Giroud-Han design equation has only been calibrated for specific geogrid types. Recalibration of the equation would be required for other types of geogrid. The Giroud-Han equation can be used for geotextiles and for geogrid.

The Caltrans design procedure allows for increasing the R-value of the subgrade when a subgrade enhancement geotextile or geogrid is used. Increasing the R-Value of the subgrade soil affects the resulting pavement design.

A summary of some of the key considerations for these design methods is presented Table 29. The correlations between R-Value, CBR, and M_r listed in Table 29, are directly reported from the noted design procedure. See Appendix P for more information about correlation of R-Value, CBR, and M_r.

Table 29. Design Procedure Comparison – Subgrade Stabilization with Geosynthetics

Design Procedure	FHWA (2008) • Based on USFS (1979) • Modified by USACE (2003)	FHWA (2008) • Based on Giroud & Han (2004)	Caltrans (2013)
Overview	Use bearing capacity factor and design curves (charts) to determine required aggregate thickness.	Use equation to calculate (iteratively) required aggregate thickness.	Increase subgrade R-value if ***subgrade enhancement*** geosynthetic is used.

Input Parameters	• Vehicle passes
	• Equivalent axle loads
	• Axle configurations
	• Tire pressures
	• Subgrade strength
	• Maximum allowed rut depth
	• Bearing capacity factor (N_C)
	  • Unreinforced = 2.8
	  • Geogrid = 5.8
		• Aperture stability modulus (J)
		  ○ Unreinforced = 0
		  ○ Geotextile = 0
		  ○ Geogrid = measure
		• Wheel load
		• Radius of tire print
		• Number of axle passes
		• Modulus ratio
		  ○ Base course resilient modulus
		  ○ Subgrade soil resilient modulus
		• Aggregate CBR
		• Subgrade CBR
		• Rut depth factor
		• Maximum rut depth
		• Bearing capacity factor (N_C)
		  ○ Unreinforced = 3.14,
		  ○ Geotextile = 5.14
		  ○ Geogrid = 5.71
		• Factor relating subgrade CBR to undrained cohesion
			• Subgrade R-value
			• Grain size
			  ○ Aggregate base
			  ○ Subgrade
			
			Geotextile:
			For R-Value <20, a design R-Value of 20 can be used with subgrade enhancement geotextile.
			
			Geogrid:
			For R-Value <25, a design R-Value of 25 can be used with subgrade enhancement geogrid.

For geotextiles?	Yes.	Yes. Use J=0, N_C = 5.14 for geotextile.	Yes, as directed by flowchart.
For geogrid?	Yes, as modified by Tingle & Webster (2003). Use N_C = 5.8 for geogrids.	Yes.	Yes, as directed by flowchart.
Use geotextile with geogrid?	Check if needed.	Check if needed.	Use unless aggregate base material meets natural filter criteria.

Table 29. Design Procedure Comparison – Subgrade Stabilization with Geosynthetics (continued)

Design Procedure	**FHWA (2008)** • **Based on USFS (1979)** • **Modified by USACE (2003)**	**FHWA (2008)** • **Based on Giroud & Han (2004)**	**Caltrans (2013)**
Accounts for different types of geogrid?	No.	Yes. Requires calibration for different types of geosynthetics (manufacturing processes, materials, etc.).	No. No additional "credit" is given for using different types of geogrid.
Limitations	• Aggregate layer must be ○ High quality fill ○ Cohesionless • Vehicle passes <10,000 • Geotextile survivability criteria must be specified • Subgrade undrained shear strength c<2000 psf (90 kPa) (CBR<3) • Based on increasing bearing capacity only. • Does not account for geogrid providing lateral restraint.	• Rut depth 2-4 inches • Field subgrade CBR < 5 • Modulus Ratio ≤ 5 • ESALs < 100,000 • Does not include tension membrane effect • ABC thickness ≥4 inches • Calibrated for two types of stiff, biaxial geogrid. Requires calibration for different types of geosynthetics (manufacturing processes, materials, etc.). • No standard (ASTM) test method for aperture stability modulus	• Geotextile may be applicable for ○ R-value<20 ○ CBR<3 ○ M_R <4,500 psi • Geogrid may be applicable for ○ R-Value <25 ○ CBR<3.5 ○ M_R <5,000 psi • Use of geogrid not recommended unless aggregate material meets natural filter criteria. ○ Use geotextile for separation and stabilization instead.

Table 29. Design Procedure Comparison – Subgrade Stabilization with Geosynthetics (continued)

Design Procedure	**FHWA (2008)** • **Based on USFS (1979)** • **Modified by USACE (2003)**	**FHWA (2008)** • **Based on Giroud & Han (2004)**	**Caltrans (2013)**
Design Steps	1. Measure soil subgrade strength 2. Determine wheel loading 3. Estimate amount of traffic 4. Establish tolerable rutting 5. Obtain bearing capacity factor (from USACE, 2003) • 2.8 without geotextile • 3.6 with nonwoven geotextile • 5.0 with woven geotextile • 5.8 with geogrid • 5.8 with geogrid and nonwoven geotextile 6. Determine required aggregate thickness • Use design curves/charts 7. Select design base course thickness 8. Specify geotextile requirements for • Drainage and filtration • Survivability	1. Measure soil subgrade strength 2. Determine wheel loading 3. Estimate amount of traffic 4. Preliminary calculations • Rut depth, radius of rut depth, undrained shear strength of subgrade soil 5. Check capacity of subgrade soil to support wheel load without reinforcement 6. Determine required base course thickness using equation • Thickness ≥ 4 in (100 mm) 7. Check need for subgrade separation geotextile with geogrid	1. Determine subgrade R-value 2. Determine grain size of subgrade • D_{15}, D_{50} 3. Use flow chart to select geotextile or geogrid

REVIEW OF PERFORMANCE-RELATED FIELD STUDIES

Field studies were reviewed to evaluate the performance of geosynthetics used for subgrade stabilizations. The following paragraphs summarize these studies.

Paper No. 06-2285 Deflection of Prototype Geosynthetic-Reinforced Working Platforms over Soft Subgrade (Kim et al. 2006)

The important conclusion that can be drawn from this study is that any type of geosynthetic can provide a benefit. The effect of a geogrid or a nonwoven geotextile is very similar. A nonwoven geotextile provides approximately 66 percent of the benefit of a geogrid at a low deflection of ½ inch with regard to reduction of gravel thickness.

Benefits of Using Geotextile between Subgrade Soil and Base Course Aggregate in Low-Volume Roads in Virginia (Shabbir and Schmidt 2009)

The benefit shown in the field portion of the study may not be accurate because of the brief evaluation period. The report states that a geotextile appears to provide reinforcement to the soil-aggregate system by reducing permanent deformation by a minimum of 20 percent for low traffic with an ADT of 650. This is from laboratory testing using cyclic loading with deformation measured at 25,000 cycles. Figures showing permanent deformation versus CBR (%) are presented for several laboratory samples.

Monitoring Geosynthetics in Local Roadways (LRRB 768) 10-Year Performance Study (Clyne 2011)

Based on the results of the study, Type V geosynthetics are not recommended in cases where increased pavement performance or longer pavement life is expected. However, pavements with geogrid did provide better ride quality, structural capacity, and cracking resistance than pavements without geogrids.

The best performance of all sections was the saw and seal section, where sawed and sealed control joints were utilized. The sealing of the pavement, which prevented moisture intrusion from random cracks that would have formed, obviously improved the long-term performance.

Eight-Year Field Performance of a Secondary Road Incorporating Geosynthetics at the Subgrade-Base Interface (Al-Qadi and Appea 2003)

Analysis of FWD data suggested that 100 mm base course sections stabilized with geotextile or geogrid had a lower Base Damage Index, almost half that of the unstabilized sections. All of the thicker aggregate base sections performed similarly for the control, geotextile, and geogrid sections. As a result, the increase of service life by utilization of geotextile or geogrids is reduced for stronger pavements, suggesting that the performance of the pavement is more dependent upon the thickness of the base course than the presence of the geotextile or geogrid. The better performance associated with the geotextile or geogrid may occur only after more traffic and increased rut depths—a higher benefit is somewhat dependent on the rut depth being greater than ½ inch. In other words, the pavement nearly has to fail in order for the geotextile or geogrid to be effective.

Field Investigation of Geosynthetics Used For Subgrade Stabilization (Cuelho and Perkins 2009)

In every case in this study, the geosynthetic did not perform as well as predicted by the FHWA design method. Reasons for premature failure were somewhat uncertain, and were possibly related to the lower in-place strength of the base course aggregate (due to rounded, coarse particles) and the high air pressure in the truck tires.

A final table shows the number of additional passes, resulting from the use of a particular geosynthetic, that achieve a specific rut depth over the control section. The table shows that for low ruts, the stronger, integrally formed geogrid and welded geogrids perform the best. However, overall, the welded geogrids performed the best since good performance continued at high rut depths where the integrally formed geogrids failed.

A figure shows the relationship between the 2 percent and 5 percent cross-machine tensile strength versus additional passes over the control section for 75 mm of rut. This figure shows that the higher the tensile strength is at 2 percentstrain, the higher the number of additional passes to achieve a specific rut depth. This stays true for 100 mm of rut as long as the material remained intact.

Review of Corps of Engineers Design of Geosynthetic-Reinforced Unpaved Roads (Tingle and Webster 2003)

The authors recommended the continued use of the USACE design method. However, the bearing capacity factor for geotextiles should be reduced to 3.6 for a conservative design. In addition, a bearing capacity factor of 5.8 is recommended when the aggregate is reinforced with geogrid and nonwoven geotextile.

SUMMARY OF PERFORMANCE-RELATED FIELD STUDIES

The performance-related field studies show that the use of a geosynthetic material may have many benefits. These benefits include the potential to extend the service life of pavement and to improve ride quality, structural capacity, and cracking resistance. The studies also show that any type of geosynthetic can provide a benefit. However, a non-woven geosynthetic may provide less benefit than a geogrid. The benefit associated with the geosynthetic increases as the rut depth increases.

The 2009 Montana State University study showed that for low ruts, integrally formed geogrid and welded geogrids performed well. However, overall, the welded geogrids performed the best because good performance continued at high rut depths, where the integrally formed geogrids failed. In addition, the 2 percent and 5 percent cross-machine tensile strength of the geogrid appears to be related to its performance. This study also showed that the higher the tensile strength is 2 percent strain, the higher the number of passes it took to achieve a specific rut depth.

RECOMMENDATIONS

Recommended design guidelines have been developed for subgrade stabilization using geotextiles and geogrids. These design guidelines are based on the design processes that were reviewed and discussed in this chapter. These design guidelines are supported by the performance-related field studies that were also reviewed in this chapter. The recommended design guidelines are generally based on the USFS design method (Steward et al. 1977) as described in FHWA NHI-07-092, with modifications based on review of other design procedures, particularly the USACE design procedure. Recommended draft design guidelines for subgrade stabilization are shown in Appendix R.

CHAPTER 6: COST COMPARISON

INTRODUCTION

The objective of this chapter is to examine the cost savings of using geosynthetics in the pavement section. The evaluation will be based on the construction costs for design alternatives with and without geosynthetics. The design alternatives will be calculated using the design procedures presented in Chapter 4 for base reinforcement and in Chapter 5 for subgrade stabilization.

This cost comparison focuses exclusively on construction costs (i.e., installed materials). Although there may also be a long-term performance difference between pavements with and without geosynthetics, there are insufficient data in the literature to arrive at a conclusion on these alternatives at this time. Therefore, the cost analysis presented in this chapter does not factor in potential life-cycle cost savings of using geosynthetics in the pavement section.

ADOT would need to conduct additional research in order to quantify the potential long-term performance difference between pavement with geosynthetics and those without. ADOT could construct test decks with and without geosynthetics to evaluate the performance difference. ADOT could also investigate the performance of pavements that have already been constructed with geosynthetics and compare it to the performance of pavements constructed without geosynthetics.

BASE REINFORCEMENT - COST ANALYSIS AND COST COMPARISON OF PAVEMENT DESIGN SECTIONS WITH AND WITHOUT GEOGRID AND GEOTEXTILE

A cost analysis of the pavement design alternatives with or without geogrid and geotextile was performed to determine the economic benefit of using a geogrid and geotextile for base reinforcement in the pavement design. The cost analysis is based on the design procedure presented in Chapter 4 for base reinforcement. The cost analysis focuses on the costs when the R-Value is less than 20. The required pavement thickness designs with or without geotextile have already been identified in the design examples presented in Chapter 4. The cost analysis may be performed using unit costs based on recent ADOT construction costs. For purposes of this cost analysis, it is assumed that a geotextile will always be used with a geogrid, since this is ADOT's normal design. ADOT typically uses geogrid and geotextile when the R-Value is less than 20. In these cases, the subgrade soil would usually have greater than 35 percent passing the No. 200 sieve. Therefore, this appears to be a reasonable approach.

Construction Costs

The ADOT *Construction Cost Summaries* for 2013 and 2014 were utilized in determining construction costs for the different items of work involved in the pavement structural section (ADOT 2013b, ADOT 2014b). The construction costs for several projects where geogrid and geotextile were used were reviewed, focusing on projects where large quantities were utilized. The costs varied somewhat by contractor but were fairly consistent. For aggregate base course, asphalt mix, and asphalt binder, the cost varied by contractor and location of the project. The costs were higher for rural projects than for metropolitan projects, and higher still for projects constructed in northeastern Arizona, where the scarcity of quality aggregate leads to increased transportation costs. The unit cost for mineral admixture in asphalt is a set cost of $90.00 per ton in every ADOT contract.

These ADOT items of work utilized in the cost analyses are listed in Table 30.

Table 30. Items of Work Utilized in Cost Analysis

Item of Work	Unit Cost Metropolitan Areas	Unit Cost Rural Areas	Unit Cost Northeastern Arizona
Geogrid	$2.00 per SY	$2.00 per SY	$2.00 per SY
Geotextile	$2.00 per SY	$2.00 per SY	$2.00 per SY
AB Class 2	$25.00 per CY	$35.00 per CY	$60.00 per CY
Asphalt Mix	$35.00 per TON	$40.00 per TON	$60.00 per TON
Asphalt Binder	$600.00 per TON	$650.00 per TON	$650.00 per TON
Mineral Admixture	$90.00 per TON	$90.00 per TON	$90.00 per TON

To compare the costs of the different alternative pavement design sections with and without geogrid and geotextile, it is necessary to estimate the cost per square yard for the different items of work listed above.

Geotextile and Geogrid Costs

ADOT typically uses geogrid and geotextile together. For geogrid and geotextile together, a cost of $4.00 per square yard is estimated in all of the cost comparisons. The unit rates for supplying and installing geogrid and geotextile did not appear to change based on location.

AB Class 2

Since the cost for aggregate base (AB Class 2) is normally paid per cubic yard, and the pavement design comparisons are measured in inches, the cost per square yard per inch must be determined.

For metropolitan areas, the cost for AB Class 2 is estimated to be $25.00 per cubic yard in place. To determine the cost per square yard per inch, the cost may be simply divided by 36 since there are 36 inches in a yard. The cost per square yard per inch for metropolitan areas would be $0.69. For rural areas, the cost of $35.00 per cubic yard would be equivalent to $0.97 per square yard per inch. In northeastern Arizona, with a unit cost of $60.00 per cubic yard, the cost per square yard per inch would increase to $1.67.

Asphalt

Since the cost for asphalt involves several items of payment, including asphalt mix, asphalt binder, and mineral admixture, and the pavement design comparisons are measured in inches, the cost per square yard per inch must be determined.

For metropolitan areas, the cost per ton for asphalt mix is $35.00 per ton. The unit weight of in-place compacted asphalt is assumed to be approximately 146 pounds per cubic foot.

The weight in pounds of asphalt mix per square yard per inch would be determined as shown in Equations 8 and 9:

$$Asphalt\ mix\ weight = 146\frac{lb}{ft^3} \times \frac{1\,ft}{12in} \times \frac{9\,ft^2}{yd^2} \quad \text{(Eq. 8)}$$

$$Asphalt\ mix\ weight = 109.5\frac{lb}{yd^2 - in} \quad \text{(Eq. 9)}$$

The cost per square yard per inch of asphalt mix would be determined as shown in Equations 10 and 11:

$$Asphalt\ mix\ cost = 109.5\frac{lb}{yd^2 - in} \times \frac{1\,ton}{2000\,lbs} \times \frac{\$35.00}{ton} \quad \text{(Eq. 10)}$$

$$Asphalt\ mix\ cost = \frac{\$1.916}{yd^2 - in} \quad \text{(Eq. 11)}$$

The binder is assumed to be 5 percent by weight of the asphalt mix. The cost per square yard per inch of asphalt binder would be determined as shown in Equation 12:

$$Asphalt\ binder\ cost = 109.5\frac{lb}{yd^2 - in} \times \frac{1\,ton}{2000\,lbs} \times \frac{\$600.00}{ton} \times 0.05 \quad \text{(Eq. 12)}$$

$$Asphalt\ binder\ cost = \frac{\$1.643}{yd^2 - in}$$

The admixture is assumed to be 1 percent by weight of the asphalt mix. The cost per square yard per inch of admixture would be determined by Equation 13:

$$Admixture\ cost = 109.5\frac{lb}{yd^2 - in} \times \frac{1\ ton}{2000\ lbs} \times \frac{\$90.00}{ton} \times 0.01 \qquad \text{(Eq. 13)}$$

$$Admixture\ cost = \frac{\$0.049}{yd^2 - in}$$

The total cost for the asphalt would be the total of the above three costs (asphalt mix, admixture, and binder). In this example, the total cost for asphalt would be:

$1.916 +$1.643 + $0.049 = $3.608 per square yard per inch.

These same calculation procedures would apply to asphalt supplied for rural areas and projects in northeastern Arizona.

Table 31 shows the asphalt costs calculated for metropolitan areas, rural areas, and northeastern Arizona, based on the unit costs in Table 30.

Table 31. Asphalt Costs

Item of Work	**Unit Cost Metropolitan Areas**	**Unit Cost Rural Areas**	**Unit Cost Northeastern Arizona**
Asphalt Mix	$1.916 per SY per inch	$2.190 per SY per inch	$3.285 per SY per inch
Asphalt Binder	$1.643 per SY per inch	$1.779 per SY per inch	$1.779 per SY per inch
Mineral Admixture	$0.049 per SY per inch	$0.049 per SY per inch	$0.049 per SY per inch
Total	$3.608 per SY per inch	$4.018 per SY per inch	$5.113 per SY per inch

Cost Comparisons for Different Design Alternatives with and Without Geogrid and Geotextile

The above unit costs were utilized in Tables 32 to 36 to calculate the cost for the pavement design alternatives previously calculated and presented in Chapter 4 for typical Arizona projects.

None of the projects used for the cost comparison are in a metropolitan area. Geogrid and geotextile are not used in concrete pavement, which is typically used in metropolitan areas instead of asphalt.

The design example shown in Table 32 is in close proximity to both the Phoenix and Tucson metropolitan areas. Therefore, it seemed reasonable to use the costs for metropolitan areas for this design example.

I-10 near Casa Grande, MP 185 to 191

The following data were used for the I-10 near Casa Grande, MP 185 to 191, example:

- Seasonal Variation Factor (SVF)=1.0.
- Reliability =99%.
- ΔPSI=1.2.
- Traffic 45,000 ADT – Both directions, assumed 70% of traffic in one direction in design lane.
- 2.3% annual growth from 2010 to 2030.
- Automobiles, 85%, Light to Medium Trucks, 5.0%, Heavy Trucks, 10.0%.
- Metropolitan area costs, Geogrid and Geotextile $4.00/SY, AC $3.608/SY/inch, AB Class 2 $0.69/SY/inch.

Table 32. I-10 Near Casa Grande – Cost Reduction

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
6	7.56	8	29	-	-		$48.87	-
16 w/geogrid	6.13	8	18.5	10.5	36.2	18.9	$54.09	-10.67%
6	7.56	9	26	-	-		$50.41	-
16 w/geogrid	6.13	9	15.5	10.5	40.4	18.9	$55.20	-9.49%
6	7.56	10	22.5	-	-		$51.61	-
16 w/geogrid	6.13	10	12.5	10	44.4	18.9	$56.31	-9.11%
6	7.56	11	19.5	-	-		$53.14	-
16 w/geogrid	6.13	11	9	10.5	53.9	18.9	$56.93	-7.12%
6	7.56	12	16.5	-	-		$54.68	-
16 w/geogrid	6.13	12	6	10.5	63.6	18.9	$58.04	-6.14%
10	6.84	8	24	-	-		$45.42	-
20 w/geogrid	5.78	8	16	8	29.6	15.5	$51.66	-13.74%
10	6.84	9	20.5	-	-		$46.62	-
20 w/geogrid	5.78	9	13	7.5	36.6	15.5	$52.77	-13.20%
10	6.84	10	17.5	-	-		$48.16	-
20 w/geogrid	5.78	10	10	7.5	42.9	15.5	$53.88	-11.89%
10	6.84	11	14.5	-	-		$49.69	-
20 w/geogrid	5.78	11	7	7.5	51.7	15.5	$54.99	-10.66%
15	6.13	7	22	-	-		$40.44	-
25 w/geogrid	5.36	7	16.5	5.5	25	12.6	$48.13	-19.03%
15	6.13	8	18.5	-	-		$41.63	-
25 w/geogrid	5.36	8	13	5.5	29.7	12.6	$48.75	-17.12%
15	6.13	9	15.5	-	-		$43.17	-
25 w/geogrid	5.36	9	10	5.5	35.5	12.6	$49.86	-15.51%
15	6.13	10	12.5	-	-		$44.71	-
25 w/geogrid	5.36	10	7	5.5	44	12.6	$50.97	-14.01%

Table 32. I-10 Near Casa Grande – Cost Reduction (continued)

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
20	5.78	6	22.5	-	-		$37.17	-
30 w/geogrid	5.02	6	17	5.5	24.4	13.2	$44.60	-19.97%
20	5.78	7	19.5	-	-		$38.71	-
30 w/geogrid	5.02	7	14	5.5	28.2	13.2	$45.71	-18.07%
20	5.78	8	16	-	-		$39.90	-
30 w/geogrid	5.02	8	10.5	5.5	34.4	13.2	$46.33	-16.10%
20	5.78	9	13	-	-		$41.44	-
30 w/geogrid	5.02	9	7.5	5.5	42.3	13.2	$47.44	-14.47%
25	5.36	5	22.5	-	-		$33.57	-
35 w/geogrid	4.75	5	18	4.5	20	11.4	$41.55	-23.79%
25	5.36	6	19.5	-	-		$35.10	-
35 w/geogrid	4.75	6	15	4.5	23.1	11.4	$42.66	-21.52%
25	5.36	7	16.5	-	-		$36.64	-
35 w/geogrid	4.75	7	12	4.5	27.3	11.4	$43.77	-19.45%
25	5.36	8	13	-	-		$37.83	-
35 w/geogrid	4.75	8	9	5	38.5	11.4	$44.87	-18.61%
30	5.02	5	20	-	-		$31.84	-
40 w/geogrid	4.51	5	16.5	3.5	17.5	10.2	$40.10	-25.93%
30	5.02	6	17	-	-		$33.38	-
40 w/geogrid	4.51	6	13.5	3.5	20.6	10.2	$41.20	-23.44%
30	5.02	7	14	-	-		$34.92	-
40 w/geogrid	4.51	7	10	4	28.6	10.2	$41.83	-19.79%
30	5.02	8	10.5	-	-		$36.11	-
40 w/geogrid	4.51	8	7	3.5	33.3	10.2	$42.93	-18.90%
35	4.75	5	18	-	-		$30.46	-
42 w/geogrid*	4.37	5	15.5	2.5	13.9	8	$39.13	-28.45%
35	4.75	6	15	-	-		$32.00	-
42 w/geogrid*	4.37	6	12.5	2.5	16.7	8	$40.23	-25.74%
35	4.75	7	12	-	-		$33.54	-
42 w/geogrid*	4.37	7	9	3	25	8	$40.86	-21.83%
35	4.75	8	9	-	-		$35.07	-
42 w/geogrid*	4.37	8	6	3	33.3	8	$41.96	-19.64%

Table 32. I-10 Near Casa Grande – Cost Reduction (continued)

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
40	4.51	5	16.5	-	-		$29.43	
42 w/geogrid*	4.37	5	15.5	1	6.1	3.1	$39.13	-32.97%
40	4.51	6	13.5	-	-		$30.96	-
42 w/geogrid*	4.37	6	12.5	1	7.4	3.1	$40.23	-29.94%
40	4.51	7	10	-	-		$32.16	-
42 w/geogrid*	4.37	7	9	1	10	3.1	$40.86	-27.06%
40	4.51	7	7	-	-		$30.09	-
42 w/geogrid*	4.37	7	6	1	14.3	3.1	$37.95	-26.13%

* Limited to a maximum resilient modulus M_r of 26,000, which is equivalent to an ADOT R-Value of 42 for a Seasonal Variation Factor (SVF) of 1.0.

Table 32 for I-10 near Casa Grande shows that using geogrid and geotextile in a metropolitan area may actually increase the construction cost. For all R-Values in this example, the cost with geogrid and geotextile was higher than the cost without. This is due to the fact that the material costs for asphalt and asphalt base are lower in metropolitan areas.

I-10 near San Simon, MP 382 to 391

The following data were used for the I-10 near San Simon, MP 382 to 391, example:

- SVF=1.6.
- Reliability=99%.
- ΔPSI=1.2.
- Traffic 12,900 ADT – Both directions, assumed 70% of traffic in one direction in design lane.
- 0.8% annual growth from 2010 to 2030.
- Automobiles, 63%, Light to Medium Trucks, 5.0%, Heavy Trucks, 32.0%.
- Rural area costs, Geogrid and Geotextile $4.00/SY, AC $4.018/SY/inch, AB Class 2 $0.97/SY/inch.

Table 33. I-10 Near San Simon

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
6	7.63	9	26	-	-		$61.38	-
16 w/geogrid	6.19	9	16	10	38.5	18.9	$55.68	9.29%
6	7.63	10	23	-	-		$62.49	-
16 w/geogrid	6.19	10	13	10	43.5	18.9	$56.79	9.12%
6	7.63	11	20	-	-		$63.60	-
16 w/geogrid	6.19	11	9.5	10.5	52.5	18.9	$57.41	9.73%
6	7.63	12	17	-	-		$64.71	-
16 w/geogrid	6.19	12	6.5	10.5	61.8	18.9	$58.52	9.56%
10	7.15	8	26	-	-		$57.36	-
20 w/geogrid	5.96	8	17.5	8.5	32.7	16.6	$53.12	7.40%
10	7.15	9	23	-	-		$58.47	-
20 w/geogrid	5.96	9	14.5	8.5	37	16.6	$54.23	7.26%
10	7.15	10	19.5	-	-		$59.10	-
20 w/geogrid	5.96	10	11	8.5	43.6	16.6	$54.85	7.18%
10	7.15	11	16.5	-	-		$60.20	-
20 w/geogrid	5.96	11	8	8.5	51.5	16.6	$55.96	7.05%
15	6.45	7	24	-	-		$51.41	-
25 w/geogrid	5.58	7	18	6	25	13.5	$49.59	3.54%
15	6.45	8	21	-	-		$52.51	-
25 w/geogrid	5.58	8	14.5	6.5	31.0	13.5	$50.21	4.39%
15	6.45	9	18	-	-		$53.62	-
25 w/geogrid	5.58	9	11.5	6.5	36.1	13.5	$51.32	4.30%
15	6.45	10	14.5	-	-		$54.25	-
25 w/geogrid	5.58	10	8.5	6	41.4	13.5	$52.43	3.36%

Table 33. I-10 Near San Simon (continued)

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
20	5.96	7	20.5	-	-		$48.01	-
30 w/geogrid	5.27	7	15.5	5	24.4	11.6	$47.16	1.77%
20	5.96	8	17.5	-	-		$49.12	-
30 w/geogrid	5.27	8	12.5	5	28.6	11.6	$48.27	1.73%
20	5.96	9	14.5	-	-		$50.23	-
30 w/geogrid	5.27	9	9.5	5	34.5	11.6	$49.38	1.69%
20	5.96	10	11	-	-		$50.85	-
30 w/geogrid	5.27	10	6	5	45.5	11.6	$50.00	1.67%
25	5.58	6	21	-	-		$44.48	-
35 w/geogrid	4.89	6	16	5	23.8	12.4	$43.63	1.91%
25	5.58	7	18	-	-		$45.59	-
35 w/geogrid	4.89	7	13	5	27.8	12.4	$44.74	1.86%
25	5.58	8	14.5	-	-		$46.21	-
35 w/geogrid	4.89	8	10	4.5	31	12.4	$45.84	0.79%
25	5.58	9	11.5	-	-		$47.32	-
35 w/geogrid	4.89	9	6.5	5	43.5	12.4	$46.47	1.80%
30	5.27	5	22	-	-		$41.43	-
40 w/geogrid	4.68	5	17.5	4.5	20.5	11.2	$41.07	0.88%
30	5.27	6	19	-	-		$42.54	-
40 w/geogrid	4.68	6	14.5	4.5	23.7	11.2	$42.17	0.86%
30	5.27	7	15.5	-	-		$43.16	-
40 w/geogrid	4.68	7	11.5	4	25.8	11.2	$43.28	-0.28%
30	5.27	8	12.5	-	-		$44.27	-
40 w/geogrid	4.68	8	8.5	4	32	11.2	$44.39	-0.27%
35	4.89	5	19	-	-		$38.52	-
45 w/geogrid	4.41	5	16	3	15.8	9.8	$39.61	-2.83%
35	4.89	6	16	-	-		$39.63	-
45 w/geogrid	4.41	6	13	3	18.8	9.8	$40.72	-2.75%
35	4.89	7	13	-	-		$40.74	-
45 w/geogrid	4.41	7	9.5	3.5	26.9	9.8	$41.34	-1.49%
35	4.89	8	10	-	-		$41.84	-
45 w/geogrid	4.41	8	6.5	3.5	35	9.8	$42.45	-1.45%
40	4.68	5	17.5	-	-		$37.07	-
50 w/geogrid	4.17	5	14	4	19	10.9	$37.67	-1.63%
40	4.68	6	14.5	-	-		$38.17	-
50 w/geogrid	4.17	6	11	3.5	20	10.9	$38.78	-1.58%
40	4.68	7	11.5	-	-		$39.28	-
50 w/geogrid	4.17	7	8	4	27.6	10.9	$39.89	-1.54%

Table 33, for I-10 near San Simon, shows the greatest cost reductions for utilization of geogrid and geotextile together when the R-Value of the subgrade soil is 15 or less. Minor cost reductions occur when the R-Value is in the range of 20 to 25. When the subgrade soils have an R-Value of over 30, either a very minor or no cost reduction is realized. For an R-Value of 35 or higher, use of a geogrid and geotextile together in the pavement section increases initial construction costs. The greater savings for the I-10 section near San Simon is likely due to the higher SVF used in the pavement design, which results in a thicker pavement section.

US-70 near Thatcher, MP 332 to 336

The following data were used for the US-70 near Thatcher, MP 332 to 336, example:

- SVF=1.6.
- Reliability=90%.
- ΔPSI=1.2.
- Traffic 8,846 ADT – Both directions, assumed 100% of traffic in one direction in design lane.
- 1.4% annual growth from 2010 to 2030.
- Automobiles, 92.5%, Light to Medium Trucks, 4.4%, Heavy Trucks, 3.1%.
- Rural area costs, Geogrid and Geotextile $4.00/SY, AC $4.018/SY/inch, AB Class 2 $0.97/SY/inch.

Table 34. US-70 Near Thatcher

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
6	5.17	4	24.5	-	-		$39.84	-
16 w/geogrid	4.03	4	16	7.5	30.6	22.1	$35.59	10.66%
6	5.17	5	21	-	-		$40.46	-
16 w/geogrid	4.03	5	13	8	38	22.1	$36.70	9.29%
6	5.17	6	18	-	-		$41.57	-
16 w/geogrid	4.03	6	10	8	44.4	22.1	$37.81	9.05%
6	5.17	7	15	-	-		$42.68	-
16 w/geogrid	4.03	7	7	8	53.3	22.1	$38.92	8.81%
10	4.79	4	21.5	-	-		$36.93	-
20 w/geogrid	3.85	4	15	6.5	30.2	19.6	$34.62	6.24%
10	4.79	5	18.5	-	-		$38.04	-
20 w/geogrid	3.85	5	12	6.5	35.1	19.6	$35.73	6.06%
10	4.79	6	15.5	-	-		$39.14	-
20 w/geogrid	3.85	6	8.5	7	45.2	19.6	$36.35	7.13%
15	4.24	4	17.5	-	-		$33.05	-
25 w/geogrid	3.56	4	13	4.5	25.7	16	$32.68	1.10%
15	4.24	5	14.5	-	-		$34.16	-
25 w/geogrid	3.56	5	9.5	5	34.5	16	$33.31	2.49%
15	4.24	6	11.5	-	-		$35.26	-
25 w/geogrid	3.56	6	6.5	5	43.5	16	$34.41	2.41%
20	3.85	4	15	-	-		$30.62	-
30 w/geogrid	3.33	4	11	4	26.7	13.5	$30.74	-0.39%
20	3.85	5	12	-	-		$31.73	-
30 w/geogrid	3.33	5	8	4	33.3	13.5	$31.85	-0.38%
25	3.56	4	13	-	-		$28.68	-
35 w/geogrid	3.06	4	9.5	3.5	26.9	14	$29.29	-2.11%

Table 34. US-70 Near Thatcher (continued)

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
30	3.33	4	11	-	-		$26.74	-
40 w/geogrid	2.92	4	8.5	2.5	22.7	12.3	$28.32	-5.89%
35	3.06	4	9.5	-	-		$25.29	-
45 w/geogrid	2.75	4	7	2.5	26.3	10.1	$26.86	-6.23%
40	2.92	4	8.5	-	-		$24.32	-
50 w/geogrid	2.74	4	6	2.5	29.4	6.2	$25.89	-6.48%

Table 34 for U.S. Route 70 (U.S. 70) near Thatcher shows a cost reduction for utilization of geogrid and geotextile together when the R-Value of the subgrade soil is 15 or less. No cost reductions occur when the R-Value for the subgrade soils is 20, and significant cost occurs when the R-Value is over 20. The lower cost savings is largely a result of lower traffic, since the SVF for this section of roadway is the same as for I-10 near San Simon.

SR-264, SR-264 to Second Mesa, MP 372 to 384

The following data were used for the SR-264, SR-264 to Second Mesa, MP 372 to 384, example:

- SVF=2.2.
- Reliability=90%.
- ΔPSI=1.5.
- Traffic 2,130 ADT – Both directions, assumed 100% of traffic in one direction in design lane.
- 0.5% annual growth from 2010 to 2030.
- Automobiles, 80%, Light to Medium Trucks, 8.0%, Heavy Trucks, 12.0%.
- Northeastern Arizona costs, Geogrid and Geotextile $4.00/SY, AC $5.113/SY/inch, AB Class 2 $1.67/SY/inch.

Table 35. SR-264, SR-264 to Second Mesa

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
6	5.17	4	24.5	-	-		$61.37	-
16 w/geogrid	4.03	4	16	7.5	30.6	22.1	$51.17	16.61%
6	5.17	5	21	-	-		$60.64	-
16 w/geogrid	4.03	5	13	8	38	22.1	$51.28	15.44%
6	5.17	6	18	-	-		$60.74	-
16 w/geogrid	4.03	6	10	8	44.4	22.1	$51.38	15.41%
6	5.17	7	15	-	-		$60.84	-
16 w/geogrid	4.03	7	7	8	53.3	22.1	$51.48	15.38%
10	4.79	4	21.5	-	-		$56.36	-
20 w/geogrid	3.85	4	15	6.5	30.2	19.6	$49.50	12.16%
10	4.79	5	18.5	-	-		$56.46	-
20 w/geogrid	3.85	5	12	6.5	35.1	19.6	$49.61	12.14%
10	4.79	6	15.5	-	-		$56.56	-
20 w/geogrid	3.85	6	8.5	7	45.2	19.6	$48.87	13.60%
15	4.24	4	17.5	-	-		$49.68	-
25 w/geogrid	3.56	4	13	4.5	25.7	16	$46.16	7.08%
15	4.24	5	14.5	-	-		$49.78	-
25 w/geogrid	3.56	5	9.5	5	34.5	16	$45.43	8.74%
15	4.24	6	11.5	-	-		$49.88	-
25 w/geogrid	3.56	6	6.5	5	43.5	16	$45.53	8.72%
20	3.85	4	15	-	-		$45.50	-
30 w/geogrid	3.33	4	11	4	26.7	13.5	$42.82	5.89%
20	3.85	5	12	-	-		$45.61	-
30 w/geogrid	3.33	5	8	4	33.3	13.5	$42.93	5.88%

Table 35. SR-264, SR-264 to Second Mesa (continued)

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
25	3.56	4	13	-	-		$42.16	-
35 w/geogrid	3.06	4	9.5	3.5	26.9	14	$40.32	4.38%
30	3.33	4	11	-	-		$38.82	-
40 w/geogrid	2.92	4	8.5	2.5	22.7	12.3	$38.65	0.45%
35	3.06	4	9.5	-	-		$36.32	-
45 w/geogrid	2.75	4	7	2.5	26.3	10.1	$36.14	0.48%
40	2.92	4	8.5	-	-		$34.65	-
50 w/geogrid	2.74	4	6	2.5	29.4	6.2	$34.47	0.51%

Table 35 for SR-264 to Second Mesa shows a significant cost reduction for utilization of geogrid and geotextile together when the R-Value of the subgrade soil is 25 or less. Minor cost reductions occur when the R-Value for the subgrade soils is over 30, and some even occurs for an R-Value of 40. The higher cost savings is largely a result of the high SVF due to the high altitude of this roadway and the high aggregate costs in northeast Arizona.

SR 86, Why to Quijotoa, MP 53 to 96

The following data were used for the SR 86, Why to Quijotoa, MP 53 to 96, example:

- SVF=1.2.
- Reliability=85%.
- ΔPSI=1.5.
- Traffic 977 ADT – Both directions, assumed 100% of traffic in one direction in design lane.
- 0.2% annual growth from 2010 to 2030.
- Automobiles, 92%, Light to Medium Trucks, 6.4%, Heavy Trucks, 1.6%.
- Rural area costs, Geogrid and Geotextile $4.00/SY, AC $4.018/SY/inch, AB Class 2 $0.97/SY/inch.

Table 36. SR 86, Why to Quijotoa

R-Value	Required SN	AC (In.)	ABC (In.)	Reduced ABC (In.)	Reduced ABC (%)	Reduced SN (%)	Total Cost per SY	Cost Reduction (%)
6	3.10	3	12.5	-	-		$24.18	-
16 w/geogrid	2.45	3	8	4.5	36	21	$23.81	1.51%
10	2.88	3	11	-	-		$22.72	-
20 w/geogrid	2.21	3	6.5	4.5	40.9	23.3	$22.36	1.61%
15	2.45	3	8	-	-		$19.81	-
25 w/geogrid	2.12	3	5.5	2.5	31.3	13.5	$21.39	-7.95%
20	2.21	3	6.5	-	-		$18.36	-
30 w/geogrid	2.00 min.	3	5	1.5	23.1	10.5	$20.90	-13.86%
25	2.12	3	5.5	-	-		$17.39	-
35 w/geogrid	2.00 Min.	3	5	0.5	9.1	5.7	$20.90	-20.21%
30	2.00 Min.	3	5	-	-		$16.90	-
40 w/geogrid	2.00 Min.	3	5	0	0	0	$20.90	-23.66%
35	2.00 Min.	3	5	-	-		$16.90	-
45 w/geogrid	2.00 Min.	3	5	0	0	0	$20.90	-23.66%
40	2.00 Min.	3	5	-	-		$16.90	-
50 w/geogrid	2.00 Min.	3	5	0	0	0	$20.90	-23.66%

Table 36 for SR 86, Why to Quijotoa, shows a minor cost reduction for utilization of geogrid and geotextile together when the R-Value of the subgrade soil is 10 or less. Significant additional costs occur for R-Values that are higher than 10. The lower cost savings is largely a result of the lower SVF due to the low altitude of this roadway, the low aggregate cost, and the lower traffic on the roadway. The minimum structural number applies when the R-Value is 30 and higher, so the pavement section is somewhat over-designed at that point.

Discussion of Cost Comparisons

The cost comparisons show that the use of geogrid and geotextile for base reinforcement may provide a cost savings when the R-Value is less than 20, depending on construction costs. In metropolitan areas where the cost of asphalt and ABC Class 2 is lower, the use of geogrid and geotextile for base reinforcement may actually increase the construction costs. In rural areas in the low desert, the use of geogrid and geotextile for base reinforcement when the R-Value is greater than 20 also results in little or no cost savings. This supports ADOT's current practice of not using geogrid and geotextile when the subgrade R-Value is 20 or greater. However, for higher elevations, and more importantly in northeastern Arizona, where more aggregate or asphalt is required and the cost of aggregate for ABC Class 2 or asphaltic concrete is high, the use of geogrid and geotextile results in significant cost savings even for R-Values of up to 25 or 30.

The use of geogrid and geotextile should be considered even when the construction cost is slightly higher than the alternative without geosynthetics, because the geogrid and geotextile may also provide long-term performance benefit. While the research suggests that a pavement structure with geogrid and geotextile will last longer and perform better over time, information is not available to quantitatively measure or calculate the benefit. In addition, when geogrid and geotextile are used together, there is little chance of contamination of the AB Class 2. Contamination of the AB Class 2 has a negative impact on the performance and durability of the pavement section. The maximum performance benefit is attained when geogrid and geotextile are used together in base reinforcement.

SUBGRADE STABILIZATION – COST ANALYSIS AND COST COMPARISON FOR VARIOUS ALTERNATIVES

An analysis of costs was performed for the use of geogrid and geotextile for various subgrade stabilization alternatives, as presented in the design procedure in Chapter 5. The design example presented in Chapter 5 was also utilized in the cost analysis example presented below:

Generally a soft subgrade has a cohesion in the range of 250 to 500 psf. An average soft soil cohesion of 375 psf is equivalent to 2.60 psi.

The subgrade bearing capacity factor is represented as cN_C where:

c = subgrade shear strength and

N_C = bearing capacity factor

Each stabilization alternative and the calculated cN_C to be entered into the design graph is presented in Table 37.

Table 37. Subgrade Bearing Capacity Factor, cN_C

Stabilization Alternative	Bearing Capacity Factor, N_c	cN_C
Unreinforced Aggregate	2.8	7.29
Aggregate with Geogrid	5.8	15.10
Aggregate with Woven Geotextile	5.0	13.02
Aggregate with Nonwoven Geotextile	3.6	9.38
Aggregate with Geogrid and Nonwoven Geotextile	5.8	15.10

For this example, the vehicle to be analyzed is a tandem-axle 14-16 cubic yard dump truck with an 11,000 lb axle load. Figure 4 is used to determine the required aggregate thickness for each stabilization alternative.

The values of $cN_{C,}$ should be entered in the graph in Figure 4 to determine the required aggregate thickness for each stabilization alternative.

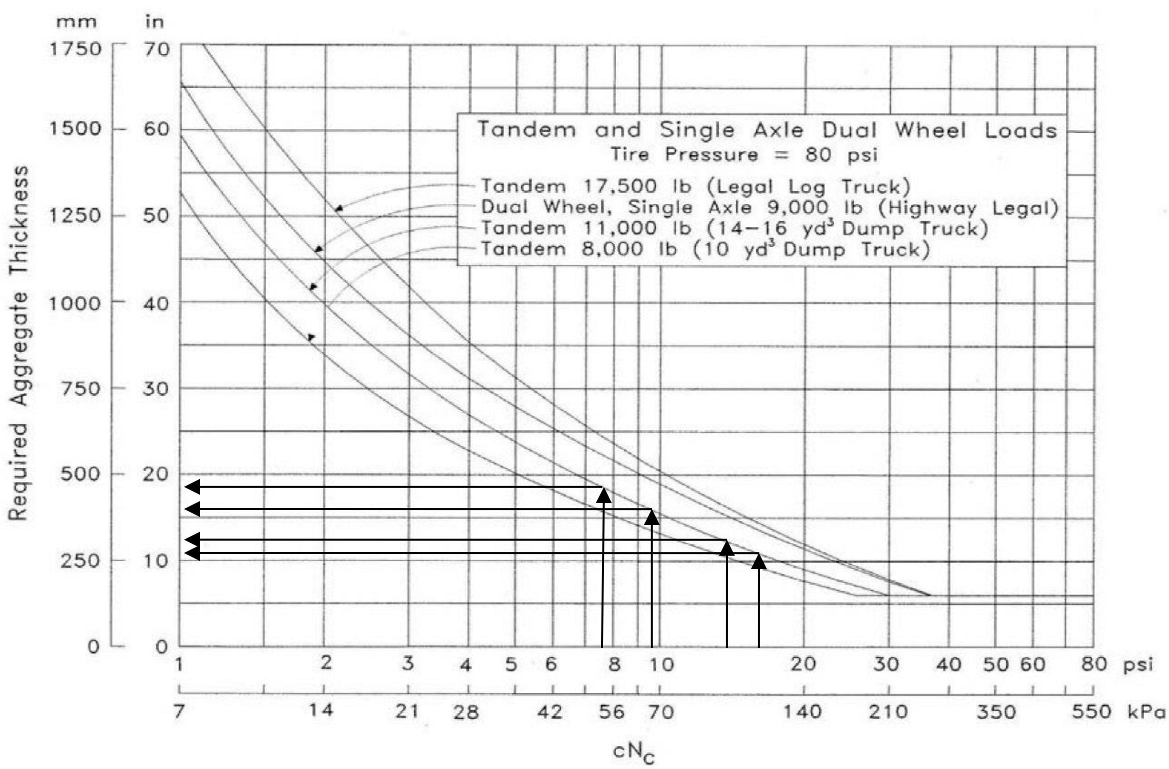

Figure 4. Subgrade Bearing Capacity vs. Aggregate Thickness (Steward et al. 1977)

The required aggregate thicknesses, rounded up to the next highest inch for each stabilization alternative, are listed in Table 38 for soft subgrade with a cohesion of 2.60 psi.

Table 38. Required Aggregate Thicknesses

Stabilization Alternative	Required Aggregate Thickness (Inches)
Unreinforced Aggregate	18
Aggregate with Geogrid	11
Aggregate with Woven Geotextile	12
Aggregate with Nonwoven Geotextile	16
Aggregate with Geogrid and Nonwoven Geotextile	11

Construction Costs

The ADOT Construction Cost Summaries for 2013 and 2014 were utilized in determining construction costs for the different items of work involved in the pavement structural section. The construction costs for several projects where geogrid and geotextile were used were reviewed, focusing on projects where large quantities were utilized. These costs are applicable to the smaller quantities used for subgrade stabilization because the costs for ABC and earthwork items are established in the contract. In addition, the costs of geosynthetics do not appear to be dependent on location. The costs varied somewhat by contractor, but were fairly consistent. The costs were higher for rural projects than for metropolitan projects, and higher still for projects constructed in northeastern Arizona, where the scarcity of quality aggregate leads to increased transportation costs. The ADOT items of work utilized in the cost analyses are listed in Table 39.

Table 39. Cost Analysis for ADOT Items of Work

Item of Work	Unit Cost Metropolitan Areas	Unit Cost Rural Areas	Unit Cost Northeastern Arizona
Geogrid	$2.00 per SY	$2.00 per SY	$2.00 per SY
Geotextile	$2.00 per SY	$2.00 per SY	$2.00 per SY
AB Class 2	$25.00 per CY	$35.00 per CY	$60.00 per CY
Roadway Excavation	$5.00 per CY	$10.00 per CY	$15.00 per CY

To compare the costs of the different subgrade stabilization alternatives, it is necessary to estimate the cost per square yard for each alternative.

Geotextile and Geogrid Costs

For geogrid and geotextile, a cost of $2.00 per square yard is estimated for geotextile and geogrid. The unit rates for supplying and installing geogrid and geotextile did not appear to change based on location.

AB Class 2

The costs for AB Class 2 have already been determined for metropolitan areas, rural areas, and in northeastern Arizona from the cost analysis for base reinforcement. These costs are $0.69 per square yard per inch for metropolitan areas, $0.97 per square yard per inch for rural areas, and $1.67 per square yard per inch for northeastern Arizona.

Roadway Excavation

Since the cost for roadway excavation is paid per cubic yard, the cost may also be converted to cost per square yard per inch by dividing the bid unit cost by 36. Therefore, the cost in metropolitan areas would be $0.14 per square yard per inch, for rural areas would be $0.28 per square yard per inch, and for northeastern Arizona would be $0.42 per square yard per inch.

Cost Comparisons

Cost comparisons were developed to compare the costs of the different subgrade stabilization alternatives for metropolitan areas, rural areas, and northeastern Arizona.

Metropolitan Areas Cost Comparison

For metropolitan areas, Table 40 shows the cost comparison between the different subgrade stabilization alternatives.

Table 40. Metropolitan Areas Cost Comparison

Item of work	Unreinforced Aggregate Cost per SY (18 inches)	Aggregate with Geogrid Cost per SY (11 inches)	Aggregate with Woven Geotextile Cost per SY (12 inches)	Aggregate with Nonwoven Geotextile Cost per SY (16 inches)	Aggregate with Geogrid and Nonwoven Geotextile Cost per SY (11 inches)
Geogrid	-	$2.00	-	-	$2.00
Geotextile	-	-	$2.00	$2.00	$2.00
AB Class 2 ($0.69)	$12.42	$7.59	$8.28	$11.04	$7.59
Roadway Excavation ($0.14)	$2.52	$1.54	$1.68	$2.24	$1.54
Total Cost	$14.94	$11.13	$11.96	$15.28	$13.13
Cost Savings	$0.00	$3.81	$2.98	-$0.34	$1.81
Percentage Savings	0%	25.5%	19.9%	-2.3%	12.1%

Rural Areas Cost Comparison

For rural areas, Table 41 shows the cost comparison between the different subgrade stabilization alternatives.

Table 41. Rural Areas Cost Comparison

Item of work	Unreinforced Aggregate Cost per SY (18 inches)	Aggregate with Geogrid Cost per SY (11 inches)	Aggregate with Woven Geotextile Cost per SY (12 inches)	Aggregate with Nonwoven Geotextile Cost per SY (16 inches)	Aggregate with Geogrid and Nonwoven Geotextile Cost per SY (11 inches)
Geogrid	-	$2.00	-		$2.00
Geotextile	-	-	$2.00	$2.00	$2.00
AB Class 2 ($0.97)	$17.46	$10.67	$11.64	$15.52	$10.67
Roadway Excavation ($0.28)	$5.04	$3.08	$3.36	$4.48	$3.08
Total Cost	$22.50	$15.75	$17.00	$22.00	$17.75
Cost Savings	$0.00	$6.75	$5.50	$0.50	$4.75
Percentage Savings	0%	30.0%	24.4%	2.2%	21.1%

Northeastern Arizona Cost Comparison

For northeastern Arizona areas, Table 42 shows the cost comparison between the different subgrade stabilization alternatives.

Table 42. Northeastern Arizona Cost Comparison

Item of work	Unreinforced Aggregate Cost per SY (18 inches)	Aggregate with Geogrid Cost per SY (11 inches)	Aggregate with Woven Geotextile Cost per SY (12 inches)	Aggregate with Nonwoven Geotextile Cost per SY (16 inches)	Aggregate with Geogrid and Nonwoven Geotextile Cost per SY (11 inches)
Geogrid	-	$2.00	-	-	$2.00
Geotextile	-	-	$2.00	$2.00	$2.00
AB Class 2 ($1.67)	$30.06	$18.37	$20.04	$26.72	$18.37
Roadway Excavation ($0.42)	$7.56	$4.62	$5.04	$6.72	$4.62
Total Cost	$37.62	$24.99	$27.08	$35.44	$26.99
Cost Savings	$0.00	$12.63	$10.54	$2.18	$10.63
Percentage Savings	0%	33.6%	28.0%	5.8%	28.3%

Discussion of Cost Comparisons

The comparisons show that when aggregate and roadway excavation costs are higher, the cost savings from using geosynthetics are also higher. Cost savings are highest for geogrid only or woven geotextile because of the higher bearing capacity factors determined for these two alternatives in the currently accepted design procedures. The cost difference between geogrid and woven geotextile is minor.

Alternative Back-Calculation of Aggregate Thicknesses Based on Current ADOT Practice

If subsurface soil strength criteria are not available, the current ADOT practice has been to remove 2 feet of the subgrade soils and utilize 24 inches of AB Class 2 in its place. Based on the bearing capacity factor of 2.8 assumed for unreinforced aggregate, the required thickness of AB Class 2 with geogrid may be back-calculated by graphically determining the cN_C value as shown in Figure 5. For an aggregate thickness of 24 inches, the cN_C value would be approximately 4.8. Dividing 4.8 by the bearing capacity factor of 2.8 for unreinforced aggregate would result in an estimated c of 1.71 psi. Using a bearing capacity factor of 5.8 for geogrid or geotextile used with geogrid, the cN_C would be 9.92. This would result in a required AB Class 2 thickness of 16 inches for geogrid or geotextile used with geogrid. For woven geotextile, using a bearing capacity factor of 5.0 results in a cN_C of 8.55, and an AB Class 2 thickness of 17.5 inches. For nonwoven geotextile, using a bearing capacity factor of 3.6 results in a cN_C of 6.16, which results in an AB Class 2 thickness of 22 inches. Cost comparisons for these five alternatives are shown in Tables 43 to 45.

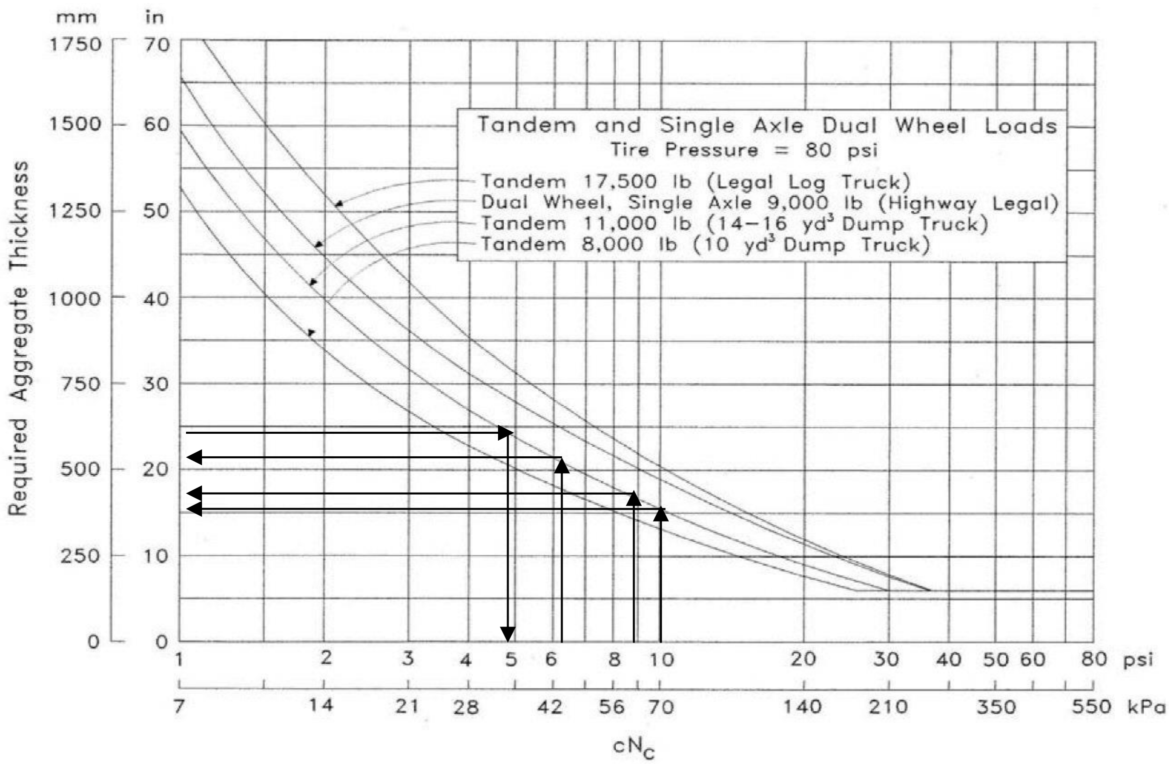

Figure 5. Subgade Bearing Capacity vs. Aggregate Thickness (Steward et al. 1977)

Cost Comparisons

Costs comparisons were developed to compare the costs of the different back-calculated subgrade stabilization alternatives for metropolitan areas, rural areas, and northeastern Arizona.

Metropolitan Areas Cost Comparison

For metropolitan areas, Table 43 shows the cost comparison between the different subgrade stabilization alternatives.

Table 43. Metropolitan Areas Cost Comparison

Item of work	Unreinforced Aggregate Cost per SY (24 inches)	Aggregate with Geogrid Cost per SY (16 inches)	Aggregate with Woven Geotextile Cost per SY (18 inches)	Aggregate with Nonwoven Geotextile Cost per SY (22 inches)	Aggregate with Geogrid and Nonwoven Geotextile Cost per SY (16 inches)
Geogrid	-	$2.00	-	-	$2.00
Geotextile	-	-	$2.00	$2.00	$2.00
AB Class ($0.69)	$16.56	$11.04	$12.42	$15.18	$11.04
Roadway Excavation ($0.14)	$3.36	$2.24	$2.52	$3.08	$2.24
Total Cost	$19.92	$15.28	$16.94	$20.26	$17.28
Cost Savings	$0.00	$4.64	$2.98	- $0.34	$2.64
Percentage Savings	0%	23.3%	15.0%	-1.7%	13.3%

Rural Areas Cost Comparison

For rural areas, Table 44 shows the cost comparison between the different subgrade stabilization alternatives.

Table 44. Rural Areas Cost Comparison

Item of work	Unreinforced Aggregate Cost per SY (24 inches)	Aggregate with Geogrid Cost per SY (16 inches)	Aggregate with Woven Geotextile Cost per SY (18 inches)	Aggregate with Nonwoven Geotextile Cost per SY (22 inches)	Aggregate with Geogrid and Nonwoven Geotextile Cost per SY (16 inches)
Geogrid	-	$2.00	-		$2.00
Geotextile	-	-	$2.00	$2.00	$2.00
AB Class ($0.97)	$23.28	$15.52	$17.46	$21.34	$15.52
Roadway Excavation ($0.28)	$6.72	$4.48	$5.04	$6.16	$4.48
Total Cost	$30.00	$22.00	$24.50	$29.50	$24.00
Cost Savings	$0.00	$8.00	$5.50	$0.50	$6.00
Percentage Savings	0%	26.67%	18.3%	1.7%	20.0%

Northeastern Arizona Cost Comparison

For areas in northeastern Arizona, Table 45 shows the cost comparison between the different subgrade stabilization alternatives.

Table 45. Northeastern Arizona Cost Comparison

Item of Work	Unreinforced Aggregate Cost per SY (24 inches)	Aggregate with Geogrid Cost per SY (16 inches)	Aggregate with Woven Geotextile Cost per SY (18 inches)	Aggregate with Nonwoven Geotextile Cost per SY (22 inches)	Aggregate with Geogrid and Nonwoven Geotextile Cost per SY (16 inches)
Geogrid	-	$2.00	-	-	$2.00
Geotextile	-	-	$2.00	$2.00	$2.00
AB Class ($1.67)	$40.08	$26.72	$30.06	$36.74	$26.72
Roadway Excavation ($0.42)	$10.08	$6.72	$7.56	$9.24	$6.72
Total Cost	$50.16	$35.44	$39.62	$47.98	$37.44
Cost Savings	$0.00	$14.72	$10.54	$2.18	$12.72
Percentage Savings	0%	29.3%	21.0%	4.3%	25.4%

SUMMARY AND CONCLUSIONS

Cost analyses were performed to evaluate the cost savings of using geosynthetics for base reinforcement and for subgrade stabilization. The cost analyses were based on installed costs of materials. Cost estimates used in this analysis were based on the ADOT *Construction Cost Summaries* for 2013 and 2014. For purposes of comparison, costs were converted to dollars per square yard per inch.

To account for different costs by region, three different categories of cost were used:

- Metropolitan construction costs.
- Rural construction costs.
- Northeastern Arizona construction costs.

Base Reinforcement

The base reinforcement analysis calculated and compared the cost of a pavement sections using geogrids and geotextiles with pavement sections that did not use these materials. The designs, with and without geosynthetics, were considered to be of equal quality. It is possible that there is a long-term performance difference between pavements using geosynthetics versus those without. However, there are insufficient data in the literature to support a conclusion.

Comparisons were developed for base reinforcement for five road segments:

- I-10 near Casa Grande, MP 185 TO 191.
- I-10 near San Simon, MP 382 TO 391.
- U.S. 70 near Thatcher, MP 332 TO 336.
- State Route 264 (SR 264) to Second Mesa, MP 372 TO 384.
- SR 86, Why to Quijotoa, MP 53 TO 96.

There is a clear benefit to using geosynthetics under the appropriate circumstances. This is demonstrated in the detailed cost-comparison tables. The greatest economic benefit from the use of geosynthetics for base reinforcement appears to occur when the R-Value is below 20.

Subgrade Stabilization

The subgrade stabilization analysis calculated and compared the cost of subgrade stabilization for five different alternatives. The costs were calculated for each of the three regions: metropolitan, rural, and northeastern Arizona. The designs, with and without geosynthetics, were considered to be of equal quality. It is possible that there is a long-term performance difference between pavements using geosynthetics versus those without. However, there are insufficient data in the literature to support a conclusion on these alternatives.

There is a clear benefit to using geosynthetics under the appropriate circumstances. This is demonstrated in the detailed cost-comparison tables. The greatest economic benefit from the use of geosynthetics for subgrade stabilization appears to occur in locations where the costs of AB Class 2 and excavation are highest.

CHAPTER 7: DRAFT SPECIFICATIONS

INTRODUCTION

The objective of Chapter 7 is to discuss the draft specifications for geotextile and geogrid products developed for review. These specifications were based on the surveys, research, evaluations, and design guidelines developed through this project. The draft specifications were written as a complete update to Section 1014, *Geosynthetics*, of the ADOT Standard Specifications. The draft specifications were formatted in accordance with ADOT Contracts and Specifications (C&S) requirements.

Section 1014 contains the material specifications for geosynthetics. Installation specifications and requirements for geosynthetic materials are presented in other sections of the ADOT Standard Specifications and in ADOT's Stored Specifications. This chapter discusses the development of the draft Section 1014 Specifications, industry feedback received on the draft specifications, changes made to the draft specifications based on industry feedback, as well as recommendations for changes to the associated installation specifications for geosynthetics.

Industry Survey

A survey was conducted to obtain feedback from the geosynthetics industry on the draft specifications and draft design guidelines developed through this project. Three industry groups were selected to review the draft specifications and draft design guidelines:

- The Geosynthetics Materials Association (GMA).
- The American Society of Civil Engineers (ASCE) Geo-Institute (G-I).
- The North American Geosynthetics Society (NAGS), also known as the International Geosynthetics Society North America Chapter (IGSNA).

A package was sent to contacts at each of the three groups containing the following:

- Cover letter.
- Study Background.
- *Draft 1014 Geosynthetics Material Specifications*.
- *Draft Guidelines for the Use of Geogrid for Base Reinforcement and Geotextile Separation Fabric*.
- *Draft Guidelines for the Use of Geogrid and Geotextile for Subgrade Stabilization*.

The packages that were sent to the industry groups are shown in Appendix S.

The group contacts were asked to circulate the documents to their members, to collect comments and feedback from their members, to compile the feedback received from their members, and to submit the comments back to ADOT on behalf of their group. All three groups participated in the survey and submitted comments on the documents. The comments are shown in Appendix T.

The comments received in the industry survey were discussed with the TAC. The draft 1014 Specifications were then revised in light of comments received in the industry survey and from the TAC. The revised draft Section 1014 Specifications are shown in Appendix U. It should be noted that not all comments received in the industry survey resulted in a change to the draft 1014 Specifications.

Review of Installation Specifications

In conjunction with developing draft Section 1014 Specifications, the installation specifications for each geosynthetic material discussed in Section 1014 were reviewed. Recommendations for changes to the installation specifications were identified and are presented in this chapter.

DRAFT SECTION 1014 SPECIFICATIONS

This section discusses updates and changes that were made to each section of the Section 1014 Specifications (ADOT 2008) in the development of the draft specifications. Additional changes that were based on comments received through the industry survey are also identified. Finally, recommendations for changes to the applicable installation specifications are also suggested.

Subsection 1014-1 General Requirements

A paragraph was added to the end of this section pointing out that the specifications for most of the materials in this section are generally based on AASHTO M288 (AASHTO 2008). The purpose of this paragraph is to help users understand the background and basis of the specification. While many of the changes in the draft specification are based on AASHTO M288, the draft specification does not fully adopt AASHTO M288.

Changes Based on Industry Survey

The industry survey included the suggestion that storage and handling of the geosynthetic materials should be in accordance with ASTM D4873-15. Although ASTM D4873 is not referenced in Subsection 1014-1, the ADOT installation specifications for geosynthetics currently reference ASTM D4873 for storage and handling in the following subsections:

- 203-5.02(B) *Geocomposite Packaging, Handling, and Storage (Geocomposite Wall Drain)*.
- 208-2.02 *Fabric Packaging, Handling, and Storage (Separation Geotextile Fabric*; will also be referenced in *Stabilization Geotextile Fabric*).
- 306-2.02 *Geogrid Packaging, Handling, and Storage (Geogrid)*.
- 307-2.02 *Geocomposite Packaging, Handling and Storage (Geocomposite Edge Drain)*.
- 412-2.04 *Fabric Packaging, Handling, and Storing (Pavement Fabric Interlayer)*.
- 913-2.05 *Bank Protection Fabric*.
- 915-2.02 *Fabric Packaging, Handling, and Storage (Temporary Silt Fence)*.

The packaging, storage, and handling specifications in each of these sections were reviewed with respect to ASTM D4873, and appropriate changes are recommended in the respective sections.

The industry survey comments also suggested that the term "fabric" be changed to "geotextile" throughout Section 1014. It is important to note that the term "fabric" is used throughout the installation specifications and in other ADOT documents. Changing the term from "fabric" to "geotextile" in Section 1014, but not in other ADOT specifications and documents, could possibly lead to confusion. This was discussed with the TAC. It was determined that the research report would recommend the change in terminology and that the implementation of the change and its effects would be further evaluated by ADOT at a later time.

Subsection 1014-2 Pavement Fabric

The pavement fabric properties and test methods revisions were based on Table 8 of AASHTO M288. It should be noted that AASHTO M288 uses the term "paving fabric" for this material instead of "pavement fabric." The TAC decided to keep the term "pavement fabric" in the ADOT specification because other ADOT specifications refer to the material as "pavement fabric." Referring to the material by two different terms could create confusion.

AASHTO M288 uses only metric units. ADOT uses English units for specifications. AASHTO metric values were converted to English units, and both units are presented in the draft specification.

Changes Based on Industry Survey

Comments received in the industry survey pointed out that the value for ultimate elongation should be ≥50 percent, in accordance with AASHTO M288. This was corrected.

The industry responses included the suggestion that requirements regarding chemical attack, rot, and mildew should be updated according to AASHTO M288. AASHTO M288 was reviewed in response to this comment. AASHTO M288 does not discuss chemical attack, rot, or mildew as related to requirements for paving fabric.

Recommendations for Changes to Installation Specifications

ADOT's installation specifications are presented in Section 412, *Pavement Fabric Interlayer*, and modified by Stored Specification 412PFL (5/08/2013). Subsection 412-2, *Materials*, refers to Subsection 1014-1 for general requirements and to Subsection 1014-2 for more specific requirements. Packaging, handling, and storage requirements are presented in Subsection 412-2.04. The packaging, handling, and storage specifications were reviewed with respect to ASTM D4873. Installation requirements are presented in Subsection 412-3, *Construction Requirements*. The installation specifications were reviewed in reference to the installation specification presented in AASHTO M288, Appendix X1.6, *Paving Fabrics*. Changes are recommended to the following subsection as indicated.

412-3.03 Surface Preparation

The pavement surface on which the fabric is to be placed shall be ~~cleaned to remove all dirt, water, oil, and any vegetation or debris~~ <u>reasonably free of dirt, water, oil, vegetation, or other debris. Cracks exceeding 1/8 inch in width shall be filled with suitable crack filler. Potholes shall be properly repaired as directed by the Engineer. Fillers shall be allowed to cure prior to placement of the pavement fabric interlayer.</u>

In addition, Subsection 412-2.04 should be updated to reflect the latest recommendations for packaging, handling, and storage in accordance with ASTM D4873. The following requirements are suggested:

- The roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage due to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.
- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.
- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geotextile or breaking of the core. Do not drag rolls.
- Store geotextiles elevated, off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Subsection 1014-3 Geogrid

The revised geogrid properties were based on the research conducted in this project. The properties specified are those most closely associated with the performance of the geogrid based on the research reviewed and in support of the design guidelines developed. The values specified were selected to represent the properties of Type II Biaxial Geogrid, which is a non-proprietary type of geogrid that is sold by multiple manufacturers.

Changes Based on Industry Survey

Comments received from the industry survey suggested that the specification should also allow for triaxial geogrids or alternate geogrid materials. The TAC requested that a specification to allow for triaxial geogrid or alternate geogrid materials be included in the research report for possible future implementation. A specification for triaxial geogrid or alternate geogrid materials was developed and is shown in Appendix V.

Industry survey comments also suggested that bonded and welded geogrids should be allowed. The draft specification was revised to allow for bonded and welded geogrids.

Other Changes

After the industry survey, a requirement for Ultraviolet Resistance was added according to the recommendations from Chapter 3.

Recommendations for Changes to Installation Specifications

ADOT installation specifications are presented in Section 306, *Geogrid Base Reinforcement*, and modified by Stored Specification 306GEOBR (5/13/2013). Subsection 306-2, *Materials*, refers to Subsection 1014-1 for general requirements and to Subsection 1014-3 for more specific requirements. Packaging, handling, and storage requirements are presented in Subsection 306-2.02. The packaging, storage, and handling specifications were reviewed with respect to ASTM D4873. Installation requirements are presented in Subsection 306-3, *Construction Requirements*. The installation specifications were also reviewed. Changes are recommended to the following subsection as indicated.

306-3.01 Weather Limitations

> The geogrid shall not be placed when weather conditions, in the opinion of the Engineer, are not suitable to allow placement or installation. This will normally be at times of wet or snowy conditions, heavy rainfall, extreme cold or frost conditions, ~~or~~ extreme heat, or excessively windy conditions.

In addition, Subsection 306-2.02 should be updated to reflect the latest recommendations for packaging, handling, and storage in accordance with ASTM D4873. The following requirements are suggested:

- When cores are required, the roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.
- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.
- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geogrid or breaking of the core. Do not drag rolls.
- Store geogrid elevated off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Subsection 1014-4 Separation Fabric

The revised separation fabric properties and test methods were based on Tables 1 and 3 of AASHTO M288. Low Survivability Fabric corresponds to AASHTO's Class 3 Geotextile. Moderate Survivability

Fabric corresponds to AASHTO's Class 2 Geotextile. High Survivability Fabric corresponds to AASHTO's Class 1 Geotextile.

AASHTO M288 uses only metric units. ADOT uses English units for specifications. AASHTO metric units were converted to English units, and both units are presented in the draft specification.

Changes Based on Industry Survey

There were no changes made to this specification in response to the industry survey.

Other Changes

After the industry survey, the TAC reconsidered the values specified for permittivity AOS. The TAC determined that a smaller opening size and higher permittivity would be more suitable for preventing fines migration from the subgrade into the asphalt base. The TAC decided to revise the permittivity to minimum 0.07 sec^{-1} and the AOS to maximum No. 70 sieve (0.22 mm).

Recommendations for Changes to Installation Specifications

Installation specifications for separation fabric are presented in Section 208, *Separation Geotextile Fabric*. Since stabilization fabric is being added as a material, this specification needs to be revised to include stabilization fabric. Subsection 208-2, *Materials*, refers to Subsection 1014-1 for general requirements and to Subsection 1014-4 for more specific requirements. Packaging, storage, and handling specifications are presented in Subsection 208-2.02. The packaging, storage, and handling specifications were reviewed with respect to ASTM D4873. The installation specifications were reviewed in reference to the installation specification presented in AASHTO M288, Appendix X1.3, *Separation/Stabilization Geotextiles*. Changes are recommended to the following subsections as indicated.

Section 208 Separation/Stabilization Geotextile Fabric

208-1 Description:

The work under this section shall consist of furnishing and placing a permeable separation or stabilization geotextile fabric. The fabric shall be placed in accordance with the details shown on the project Plans and the requirements of these specifications.

208-2 Materials:

208-2.01 Geotextile Fabric:

The separation geotextile fabric shall be supplied in accordance with and conform to the material requirements of Subsections 1014-1 and 1014-4. The stabilization fabric shall be supplied in accordance with and conform to the material requirements of Subsections 1014-1 and 1014-10. For separation fabric, special attention shall be given to the required survivability of the fabric material which will be as called out in the Special Provisions or as shown on the plans.

208-3 Construction Requirements:

208-3.01 Weather Limitations:

Separation and stabilization geotextile fabric shall not be placed when weather conditions, in the opinion of the Engineer, are not suitable to allow placement or installation. This will normally be at times of wet or snowy conditions, heavy rainfall, extreme cold or frost conditions, ~~or~~ extreme heat, or excessively windy conditions.

No changes are recommended for **Subsection 208-3.02 Equipment.**

208-3.03 Surface Preparation:

The surface upon which the separation or stabilization fabric will be placed shall be ~~compacted and finished according to the requirements of these specifications~~ prepared by clearing, grubbing, and excavating or filling the area to the design grade. This includes removal of topsoil and vegetation in accordance with Section 201. The surface shall be compacted and finished according to Subsection 205-3.04 or as approved by the Engineer. Soft spots and unsuitable areas will be identified during the subgrade preparation or subsequent proof rolling. These areas shall be excavated and backfilled with select material as approved by the Engineer and compacted in accordance with the requirements of Subsection 205-3.04.

208-3.04 Fabric Placement:

The separation or stabilization geotextile fabric shall be unrolled on the finished surface in the direction of traffic and laid smooth without wrinkles or folds. The placement of the fabric by dragging across the finished surface will not be allowed. The geotextile fabric shall be overlapped a minimum 24 inches for longitudinal and transverse joints. The center of a longitudinal overlapped joint shall be located in the same manner as a longitudinal pavement joint according to Subsection 406-6. Transverse joints shall be in the direction of aggregate placement.

On curves, the geotextile may be folded or cut to conform to the curves. The fold or overlap shall be in the direction of construction and held in place by pins, staples, or piles of fill or rock.

Prior to being covered, the geotextile shall be inspected to ensure that the geotextile has not been damaged (i.e., holes tears, rips) during installation. The inspection shall be done by the

Engineer or a representative designated by the Engineer. Damaged geotextiles, as identified by the Engineer, shall be repaired immediately. Cover the damaged area with a geotextile patch that extends an amount equal to three feet on all sides beyond the damaged area.

208-3.05 Placement and Compaction of Aggregate:

Aggregate materials shall be placed by ~~back dumping the aggregate in a manner which does not damage the fabric and then spreading the aggregate material onto the geotextile fabric in a constant forward direction~~ end dumping onto the geotextile from the edge of geotextile or over previously placed aggregate materials. The aggregate shall be placed such that the minimum specified lift thickness shall be between the geotextile and equipment tires and tracks at all times. The aggregate materials shall be spread onto the geotextile fabric in a constant forward direction. Traffic or construction equipment shall not be permitted directly on the geotextile unless approved by the Engineer for emergency purposes. In stabilization applications, the use of vibratory equipment should not be permitted until a minimum of 12 inches of aggregate covers the geotextile, or damage to the geotextile may occur. Pins or piles of aggregate can be used to hold the geotextile in place while being covered.

Overstressing the subgrade soil shall be avoided by utilizing equipment in spreading and dumping that exerts only moderate pressure on the soil. If ruts of two inches or greater occur in the aggregate, the contractor shall use lighter equipment which transmits less ground pressure. Any ruts which develop during spreading or compacting aggregate shall be filled with additional aggregate rather than bladed from adjacent areas so that the final design aggregate thickness is maintained. Construction traffic shall not be allowed to turn or stop suddenly on the aggregate placed over the geotextile fabric.

Aggregate base shall be compacted as specified in Subsection 303-3.02. Aggregate base material shall not be mixed or processed on the separation or stabilization geotextile fabric. The aggregate base material shall be premixed at the stockpile area or at another location in a manner approved by the Engineer. Aggregate base materials will be sampled for acceptance after premixing and prior to placement on the separation or stabilization fabric. Contamination and segregation of aggregate base materials prior to or during placement shall be minimized.

Any damage to the fabric occurring during placement of the aggregate must be repaired immediately. The aggregate shall be removed from the damaged area to allow placement of a fabric patch extending three feet on all sides beyond the damaged area, followed by replacement of the aggregate.

208-4 Method of Measurement:

Separation or stabilization geotextile fabric will be measured by the square yard in-place. Measurement will be measured to the nearest square yard. No allowance will be made for material in laps.

208-5 Basis of Payment:

The accepted quantity of separation or stabilization fabric, measured as provided above, will be paid for at the contract unit price per square yard, which price shall be full compensation for furnishing all labor, materials, and equipment, and performing all operations in connection with placing the separation or stabilization geotextile fabric as shown on the project plans. No payment will be made for separation or stabilization geotextile fabric rejected, or patches which are necessary, due to either contamination or damage due to either the fault or negligence of the contractor.

In addition, Subsection 208-2.02 should be updated to reflect the latest recommendations for packaging, handling, and storage in accordance with ASTM D 4873. The following requirements are suggested:

- The roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.
- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.
- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geotextile or breaking of the core. Do not drag rolls.
- Store geotextiles elevated off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Subsection 1014-5 Bank Protection Fabric

The revised bank protection fabric strength requirements and test methods were based on Tables 1 and 6 of AASHTO M288. In Table 6 of AASHTO M288, the strength class of the geotextile is based on whether the geotextile is a woven monofilament or not. In addition, three different values are specified for the permittivity and AOS properties, and selection of the values is based on soil grain size analysis. To simplify selection of materials for projects, the TAC decided to consolidate the three values into one specification that could meet all three requirements for permittivity and AOS. Available products were reviewed to determine whether there are products that can meet the consolidated requirements for permittivity and AOS. It was determined that several non-woven geotextiles can meet the consolidated requirements. However, there were no woven monofilament products that could meet the consolidated requirements. Therefore, consolidating the permittivity and AOS requirements has the effect of eliminating woven monofilament geotextiles. As a result, the specification allows only Class 1 non-woven geotextiles.

AASHTO M288 calls this material “permanent erosion control geotextile.” ADOT calls this material “bank protection fabric.”

AASHTO M288 uses only metric units. ADOT uses English units for specifications. AASHTO metric values were converted to English units, and both units are presented in the draft specification.

Changes Based on Industry Survey

There were no changes made to this specification in response to the industry survey.

Recommendations for Changes to Installation Specifications

The material requirements for bank protection fabric are presented in Subsection 913-2.05, *Bank Protection Fabric*, which refers to Subsection 1014-1 for general requirements and Subsection 1014-5 for more specific requirements. Special attention is given to the required survivability, but there is only one survivability category in the new specification; therefore, the sentence about survivability should be deleted. Packaging, handling, and storage requirements are also presented in Subsection 913-2.05. The packaging, storage, and handling specifications were reviewed with respect to ASTM D4873. The installation specifications are presented in Subsection 913-3.02, *Bank Protection Fabric*. The installation specification was reviewed in reference to the installation specifications presented in AASHTO M288, Appendix X1.4, *Erosion Control Geotextiles*. Changes are recommended to the following subsections as indicated.

913-2.05 Bank Protection Fabric:

Fabric shall be supplied in accordance with and conform to the material requirements of Subsections 1014-1 and 1014-5 respectively. ~~Special attention shall be given to the required survivability of the fabric.~~

The identification, packaging, handling, and storage of the geotextile fabric shall be in accordance with ASTM D4873. Fabric rolls shall be furnished with suitable wrapping for protection against moisture and extended ultraviolet exposure prior to placement. Each roll shall be labeled or tagged to provide product identification sufficient to determine the product type, manufacturer, quantity, lot number, roll number, date of manufacture, shipping date, and the project number and name to which it is assigned. Rolls will be stored on the site or at another identified storage location in a manner which protects them from the elements. If stored outdoors, they shall be elevated and protected with a waterproof, light colored, opaque cover. At no time, shall the fabric be exposed to sunlight for a period exceeding 14 days.

913-3.02 Bank Protection Fabric:

When fabric is required, it shall be placed in the manner and at the locations shown on the project plans. The surface to receive the fabric shall be free of obstructions, depressions, and debris. ~~The fabric shall be loosely laid and not placed in stretched conditions.~~The geotextile shall be placed in intimate contact with the soils without wrinkles or folds and anchored on a smooth grade surface approved by the Engineer. The geotextile shall be placed in such a manner that placement of the overlying materials will not excessively stretch the geotextile so as to tear it. Anchoring of the terminal ends of the geotextile shall be accomplished through the use of key trenches or aprons at the crest and toe of the slope.

~~The strips shall be placed to provide a minimum 24 inches of overlap to each joint.~~The geotextile shall be placed with the machine direction parallel to the direction of water flow, which is normally parallel to the stream or channel in the case of stream bank and channel protection. Adjacent geotextile sheets shall be joined by overlapping 24 inches (horizontal joints). Overlapped roll ends or sides shall be a minimum of 24 inches (vertical joints). On horizontal joints, the uphill strip shall overlap the downhill strip. On vertical joints, the upstream strip shall overlap the downstream strip. The fabric shall be protected at all times during construction from extensive exposure to sunlight.

Care should be taken during installation so as to avoid damage occurring to the geotextile as a result of the installation process. Should the geotextile be damaged during installation, a geotextile patch shall be placed over the damage area extending three feet beyond the perimeter of the damage.

The riprap placement shall begin at the toe of the slope and proceed up the slope. Placement shall take place so as to avoid stretching and subsequent tearing of the fabric. Riprap and heavy stone filling shall not be dropped from a height of more than 6 inches. Stone with a weight of more than 200 pounds shall not be allowed to roll down the slope.

When the maximum size of the rock to be placed on the fabric exceeds 18 inches, the fabric shall be protected during the placement of rock by a layer of bedding material. The bedding material shall be spread uniformly on the fabric to a depth of four inches and shall be free of mounts, dips, or windrows. Compaction of the bedding material will not be required.

Rock shall be carefully placed on the bedding material and fabric in such a manner as not to damage the fabric. If, in the opinion of the Engineer, the fabric is damaged or displaced to the extent that it cannot function as intended, the contractor shall remove the rock, regrade the area if necessary, and replace the fabric.

Following placement of the riprap, grading of the slope shall not be permitted if the grading results in movement of the riprap directly above the geotextile.

Any geotextile damaged during riprap or backfill placement shall be replaced as directed by the Engineer at the contractor's expense.

In addition, Subsection 913-2.05 should be updated to reflect the latest recommendations for packaging, handling, and storage in accordance with ASTM D4873. The following requirements are suggested:

- The roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.
- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.
- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geotextile or breaking of the core. Do not drag rolls.
- Store geotextiles elevated off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Subsection 1014-6 Geocomposite Wall Drain System

The revised properties for geocomposite wall drain core were based on the recommendations of Chapter 3.

Changes Based on Industry Survey

There were no changes made to this specification in response to the industry survey.

Recommendations for Changes to Installation Specifications

Material requirements for geocomposite wall drain are presented in Subsection 203-5.02 (A), *Geocomposite Drain*; this subsection is for a geocomposite wall drain and refers to Subsection 1014-1 for general requirements and to Subsection 1014-6 for more specific requirements. Geocomposite packaging, handling, and storage requirements are presented in Subsection 203-5.02 (B). The packaging, storage, and handling specifications were reviewed with respect to ASTM D4873. Installation requirements are presented in Subsection 203-5.03 (C), *Geocomposite Wall Drain*, and modified by Stored Specification 203ERWK (3/23/2011). A review of the installation specification was completed, and the installation specification still appears to be applicable at this time.

Subsection 203-5.02(B) should be updated to reflect the latest recommendations for packaging, handling, and storage in accordance with ASTM D4873. The following requirements are suggested:

- The roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.
- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.
- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geocomposite or breaking of the core. Do not drag rolls.
- Store geocomposites elevated off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Subsection 1014-7 Geocomposite Edge Drain System

The revised properties for geocomposite edge drain core were based on the recommendations of Chapter 3.

Changes Based on Industry Survey

There were no changes made to this specification in response to the industry survey.

Recommendations for Changes to Installation Specifications

Installation specifications for geocomposite edge drains are presented in Section 307, *Geocomposite Edge Drain*, which refers to Subsection 1014-1 for general requirements and to Subsection 1014-6 for more specific requirements. Packaging, storage, and handling requirements are presented in Subsection 307-2.02. The packaging, storage, and handling specifications were reviewed with respect to ASTM D4873. Installation requirements are presented in Subsection 307-3, *Construction Requirements*. A review of the construction requirements specification was completed, and the specification appears to still be applicable.

Subsection 307-2.02 should be updated to reflect the latest recommendations for packaging, handling, and storage in accordance with ASTM D4873. The following requirements are suggested:

- The roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.

- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.
- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geocomposite or breaking of the core. Do not drag rolls.
- Store geocomposites elevated off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Subsection 1014-8 Temporary Silt Fence

The revised temporary silt fence properties and test methods were based on Table 7 of AASHTO M288.

AASHTO M288 uses only metric units. ADOT uses English units for specifications. AASHTO metric units were converted to English units, and both units are presented in the draft specification.

Changes Based on Industry Survey

The industry survey responses included the suggestion that a strength requirement for polymeric mesh should be added, and proposed wording was provided. The proposed requirement was incorporated into the draft specification.

Other Changes

After the industry survey, the temperature in the last paragraph of the proposed specification was revised to match the recommended changes to the installation specifications described as follows.

Recommendations for Changes to Installation Specifications

Installation specifications for temporary silt fence fabric are presented in Section 915, *Temporary Silt Fence*. Material requirements are presented in Subsection 915-2.01, *Geotextile Fabric*, which refers to Subsection 1014-1 for general requirements and Subsection 1014-8 for more specific requirements. Packaging, handling, and storage requirements are presented in Subsection 915-2.02. The packaging, storage, and handling specifications were reviewed with respect to ASTM D4873. Installation specifications were reviewed in reference to the installation specifications presented in AASHTO M288 Appendix X1.5, *Silt Fence Geotextiles*. Changes are recommended to the following subsections as indicated.

915-2 Materials:

915-2.04 Wire Support Fence:

Wire support fence shall be a minimum of 32 inches high and shall be ~~12~~ 14 gauge steel wire mesh or prefabricated polymeric mesh meeting the requirements of Section 1014-8. Wire support fences having at least six horizontal wires and vertical wire a maximum of 6 inches apart should be utilized.

915-3 Construction Requirements:

915-3.01 Silt Fence Installation:

The contractor shall install a temporary silt fence as shown on the plans and at other locations as directed or approved by the Engineer.

Fence construction shall be adequate to handle the stress from sediment loading. ~~Geotextile at the bottom of the fence shall be buried a minimum of six inches in a trench so that no flow can pass under the barrier.~~The geotextile at the bottom of the fence shall be buried in a "J" configuration to a minimum depth of six inches in a trench so that no flow can pass under the silt fence. The trench shall be backfilled and the soil compacted over the geotextile. Fence height shall be as specified by the Engineer but in no case shall exceed 36 inches above the ground surface.

915-3.02 Post Installation:

Posts shall be set a minimum of 18 inches into the ground and spaced ~~a maximum of six feet apart~~ according to Section 1014-8. The embedment depth shall be increased to 24 inches if the fence is placed on a slope of 3:1 H:V or steeper. Where ~~an 18-inch post~~ the specified embedment depth is impossible to achieve, the posts shall be adequately secured to prevent overturning of the fence due to sediment loading and ponding pressure.

915-4 Maintenance Requirements:

915-4.01 Silt Fence Maintenance:

The contractor shall be responsible to maintain the integrity of silt fences as long as necessary to contain sediment runoff in accordance with Subsection 104.09, or as directed by the Engineer.

<u>The contractor shall inspect all temporary silt fences immediately after each rainfall and at least daily during prolonged rainfall. The contractor shall immediately correct any deficiencies.</u>

<u>The contractor shall also make a daily review of the location of silt fences in areas where construction activities have altered the natural contours and drainage runoff to ensure that the silt fences are properly located for effectiveness. Where deficiencies exist as determined by the Engineer, additional silt fences shall be installed as directed by the Engineer.</u>

<u>Damage or otherwise ineffective silt fences shall be repaired and replaced promptly.</u>

In addition, Subsection 915-2.02 should be updated to reflect the latest recommendations for packaging, handling, and storage in accordance with ASTM D4873. The following requirements are suggested:

- The roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.
- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.
- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geotextile or breaking of the core. Do not drag rolls.
- Store geotextiles elevated off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Section 1014-9 Drainage Fabric

The revised drainage fabric strength requirements and test methods were based on Tables 1 and 2 of AASHTO M288. In Table 2, three different values are specified for the permittivity and AOS properties, and selection of the values is based on soil grain size analysis. To simplify selection of materials for projects, the TAC decided to consolidate the three values into one specification that could meet all three requirements for permittivity and AOS. Available products were reviewed to determine whether there are products that can meet the consolidated requirements for permittivity and AOS. It was determined that several non-woven geotextiles can meet the consolidated requirements. However, there were no woven monofilament products that could meet the consolidated requirements. Therefore, consolidating the permittivity and AOS requirements has the effect of eliminating woven geotextiles. As a result, the specification allows only Class 2 non-woven geotextiles.

Changes Based on Industry Survey

There were no changes made to this specification in response to the industry survey.

Recommendations for Changes to Installation Specifications

Material requirements for drainage geotextile are presented in Subsection 506-2.04, *Drainage Geotextile Fabric*, which refers to Subsection 1014-9 for specific requirements. However, it should also refer to Subsection 1014-1 for general requirements. There are no requirements for fabric packaging, handling, and storage. Installation requirements are presented in Subsection 506-3, *Construction Requirements*, and more specifically in Subsection 506-3.03, *Fabric Placement*, and Subsection 506-3.04, *Underdrain Construction Details*. The installation specifications were reviewed in reference to the installation specification presented in AASHTO M288, Appendix X1.2, *Drainage Geotextiles*. Changes are recommended to the following subsection as indicated.

506-2.04 Drainage Geotextile Fabric:

The drainage geotextile fabric shall be as specified in Subsection<u>s 1014-1 and</u> 1014-9.

<u>The identification, packaging, handling, and storage of the geotextile fabric shall be in accordance with ASTM D4873. Fabric rolls shall be furnished with suitable wrapping for protection against moisture and extended ultraviolet exposure prior to placement. Each roll shall be labeled or tagged to provide product identification sufficient to determine the product type, manufacturer, quantity, lot number, roll number, date of manufacture, shipping date, and the project number and name to which it is assigned. Rolls will be stored on the site or at another identified storage location in a manner which protects them from the elements. If stored outdoors, they shall be elevated and protected with a waterproof, light colored, opaque cover.</u>

In addition, a section should be added to address the latest recommendations for packaging, handling, and storage in accordance with ASTM D4873. The following requirements are suggested:

- The roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.
- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.

- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geotextile or breaking of the core. Do not drag rolls.
- Store geotextiles elevated off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Subsection 1014-10 Stabilization Fabric:

A specification for stabilization fabric was added. The stabilization fabric strength requirements and test methods are based on Tables 1 and 5 of AASHTO M288.

Changes Based on Industry Survey

There were no changes made to this specification in response to the industry survey.

Recommendations for Changes to Installation Specifications

There are no existing installation specifications for stabilization fabric. The installation specifications for separation fabric can be revised to include stabilization fabric. The installation specifications for separation fabric were reviewed in reference to AASHTO M288, Appendix X1.3, *Separation/Stabilization Geotextiles*. The following changes are recommended.

Section 208 Separation<u>/Stabilization</u> Geotextile Fabric

208-1 Description:

The work under this section shall consist of furnishing and placing a permeable separation or <u>stabilization</u> geotextile fabric. The fabric shall be placed in accordance with the details shown on the Project Plans and the requirements of these specifications.

208-2 Materials:

208-2.01 Geotextile Fabric:

The separation geotextile fabric shall be supplied in accordance with and conform to the material requirements of Subsections 1014-1 and 1014-4. <u>The stabilization fabric shall be supplied in accordance with and conform to the material requirements of Subsections 1014-1 and 1014-10. For separation fabric,</u> special attention shall be given to the required survivability of the fabric material, which will be as called out in the Special Provisions or as shown on the plans.

208-3 Construction Requirements:

208-3.01 Weather Limitations:

Separation and stabilization geotextile fabric shall not be placed when weather conditions, in the opinion of the Engineer, are not suitable to allow placement or installation. This will normally be at times of wet or snowy conditions, heavy rainfall, extreme cold or frost conditions, ~~or~~ extreme heat, or excessively windy conditions.

No changes are recommended for **Subsection 208-3.02 Equipment.**

208-3.03 Surface Preparation:

The surface upon which the separation or stabilization fabric will be placed shall be ~~compacted and finished according to the requirements of these specifications~~ prepared by clearing, grubbing, and excavating or filling the area to the design grade. This includes removal of topsoil and vegetation in accordance with Section 201. The surface shall be compacted and finished according to Subsection 205-3.04 or as approved by the Engineer. Soft spots and unsuitable areas will be identified during the subgrade preparation or subsequent proof rolling. These areas shall be excavated and backfilled with select material as approved by the Engineer and compacted in accordance with the requirements of Subsection 205-3.04.

208-3.04 Fabric Placement:

The separation or stabilization geotextile fabric shall be unrolled on the finished surface in the direction of traffic and laid smooth without wrinkles or folds. The placement of the fabric by dragging across the finished surface will not be allowed. The geotextile fabric shall be overlapped a minimum 24 inches for longitudinal and transverse joints. The center of a longitudinal overlapped joint shall be located in the same manner as a longitudinal pavement joint according to Subsection 406-6. Transverse joints shall be in the direction of aggregate placement.

On curves, the geotextile may be folded or cut to conform to the curves. The fold or overlap shall be in the direction of construction and held in place by pins, staples, or piles of fill or rock.

Prior to being covered, the geotextile shall be inspected to ensure that the geotextile has not been damaged (i.e., holes tears, rips) during installation. The inspection shall be done by the Engineer or his designated representative. Damaged geotextiles, as identified by the Engineer, shall be repaired immediately. Cover the damaged area with a geotextile patch that extends an amount equal to three feet on all sides beyond the damaged area.

208-3.05 Placement and Compaction of Aggregate:

Aggregate materials shall be placed by ~~back dumping the aggregate in a manner which does not damage the fabric and then spreading the aggregate material onto the geotextile fabric in a constant forward direction~~ end dumping onto the geotextile from the edge of geotextile or over previously placed aggregate materials. The aggregate shall be placed such that the minimum specified lift thickness shall be between the geotextile and equipment tires and tracks at all times. The aggregate materials shall be spread onto the geotextile fabric in a constant forward direction. Traffic or construction equipment shall not be permitted directly on the geotextile unless approved by the Engineer for emergency purposes. In stabilization applications, the use of vibratory equipment should not be permitted until a minimum of 12 inches of aggregate covers the geotextile, or damage to the geotextile may occur. Pins or piles of aggregate can be used to hold the geotextile in place while being covered.

Overstressing the subgrade soil shall be avoided by utilizing equipment in spreading and dumping that exerts only moderate pressure on the soil. If ruts of two inches or greater occur in the aggregate, the contractor shall use lighter equipment which transmits less ground pressure. Any ruts which develop during spreading or compacting aggregate shall be filled with additional aggregate rather than bladed from adjacent areas so that the final design aggregate thickness is maintained. Construction traffic shall not be allowed to turn or stop suddenly on the aggregate placed over the geotextile fabric.

Aggregate base shall be compacted as specified in Subsection 303-3.02. Aggregate base material shall not be mixed or processed on the separation or stabilization geotextile fabric. The aggregate base material shall be premixed at the stockpile area or at another location in a manner approved by the Engineer. Aggregate base materials will be sampled for acceptance after premixing and prior to placement on the separation or stabilization fabric. Contamination and segregation of aggregate base materials prior to or during placement shall be minimized.

Any damage to the fabric occurring during placement of the aggregate must be repaired immediately. The aggregate shall be removed from the damaged area to allow placement of a fabric patch extending three feet on all sides beyond the damaged area, followed by replacement of the aggregate.

208-4 Method of Measurement:

Separation or stabilization geotextile fabric will be measured by the square yard in-place. Measurement will be measured to the nearest square yard. No allowance will be made for material in laps.

208-5 Basis of Payment:

The accepted quantity of separation or stabilization fabric, measured as provided above, will be paid for at the contract unit price per square yard, which price shall be full compensation for furnishing all labor, materials, and equipment, and performing all operations in connection with placing the separation or stabilization geotextile fabric as shown on the project plans. No payment will be made for separation or stabilization geotextile fabric rejected, or patches which are necessary, due to either contamination or damage due to either the fault or negligence of the contractor.

In addition, Subsection 208-2.02 should be updated to reflect the latest recommendations for packaging, handling, and storage in accordance with ASTM D4873. The following requirements are suggested:

- The roll core shall have a crushing strength sufficient to avoid collapse or other damage in normal use.
- The roll shall be covered with an opaque material for protection from damage to shipment, water, sunlight, undesirable chemicals, or any other environmental condition that may damage the physical property values of the geosynthetic.
- Each roll shall be labeled with the name of the manufacturer or supplier, the product or style number, and the unique roll number. The label shall also include the roll length and width. The label shall be on the core or on the outer package.
- Use forklifts or slings to unload and transfer rolls to prevent damage to the wrapping or the geotextile or breaking of the core. Do not drag rolls.
- Store geotextiles elevated off the ground.
- Do not store geotextiles at temperatures in excess of 160°F (71°C) or below 32°F (0°C).

Stored Specification 208GEOM for Geomembrane

Stored Specification 208GEOM (12/03/1991) presents material requirements for geomembrane. The research team recommends revisions to the specification based on a review of current ADOT and other state DOT specifications as documented in Chapter 3, as well as standards from FHWA and USFS. Recommended revisions to material requirements in Stored Specification 208GEOM are presented in Appendix W.

Changes Based on Industry Survey

The geomembrane specification was not included in the industry survey because it is not part of Section 1014, *Geosynthetics*.

Recommendations for Changes to Installation Specifications

Installation specifications for geomembrane are also presented in Stored Specification 208GEOM (12/03/1991). The revised installation specifications were based on a review of current ADOT and other state DOT specifications, as well as standards from FHWA and USFS. Recommended changes to installation specifications in Stored Specification 208GEOM are presented in Appendix W.

SUMMARY

Draft material specifications for geosynthetics were developed to update Section 1014 of ADOT's *Standard Specifications for Road and Bridge Construction*. The draft specifications are based on current industry standards and test methods. The draft specifications are also in support of the design guidelines that were developed for base reinforcement and subgrade stabilization.

The draft specifications were shared with three industry groups to get feedback. All three industry groups submitted comments on the draft specifications. The comments were discussed with the TAC for the project, and changes to the draft specifications were identified and implemented.

In conjunction with the development of updated material specifications for geosynthetics, the ADOT installation specifications for geosynthetics were reviewed with respect to current industry standards and practices. Revisions to the installation specifications were recommended as appropriate.

These tasks represent a complete review and update of all material and installation specifications related to the use of geosynthetics.

RECOMMENDATIONS

While the research suggests that a pavement structure with geogrid and geotextile will last longer and perform better over time, information is not currently available to quantitatively measure or calculate the long-term benefit. The economic viability of using geosynthetics can be based on construction cost comparisons. However, it is recommended that test sections be constructed at several locations on subgrade soils with an R-Value of 20 or less to determine the long-term performance of the recommended pavement sections with geotextile and geogrid. These pavement sections should be compared to pavement sections without geotextile and geogrid for at least a 10-year period, monitoring pavement section performance and performing tests such as falling weight deflectometer tests, which are used to evaluate the strength of the pavement section in place, at least every two years.

In addition, if pavement sections already exist where geotextile and geogrid have been utilized, these pavement sections should be identified and evaluated in a similar manner. This is a possible future research area that can be utilized to help define the long-term benefit of the use of geogrid and geotextile together in pavement sections.

CHAPTER 8: FINDINGS AND RECOMMENDATIONS

The purpose of this research effort was to review and update the ADOT geosynthetic specifications for geogrids, geotextiles, geomembranes, and composites. The goal was to use the revised ADOT specifications as a tool for utilizing and maximizing the benefits of current geosynthetics and to place ADOT in a better position to evaluate new developments in this field.

This study included many steps. First, other states were surveyed to determine their practices regarding the use of geosynthetics. Next, the available ADOT specifications for geosynthetics were reviewed and compared to the information obtained in the survey. The third step was to identify available design methods for base reinforcement and subgrade stabilization using geosynthetics. The design methods were evaluated and used as a basis for developing design guidelines for ADOT. The cost savings of using geosynthetics in accordance with the developed design guidelines was analyzed for several design scenarios. Finally, draft revised specifications for geosynthetics were produced. The draft revised specifications were developed to support the recommended design guidelines and to reflect the current state of the industry. The findings and recommendations from each of these steps are summarized in this chapter.

SURVEY

The research team collected information on geosynthetics use and practices from other state DOTs. Information from 32 states was obtained through an e-mail survey. In addition, 48 state specifications (from all states except Arizona and Nevada) were accessed for review and evaluation.

Findings

- Current state specifications encompass a wide variety of applications, specified geosynthetic types, and design guidelines.
- There is no consensus among the states about how to use AASHTO M288.
- About half of the states have their own specifications and do not refer to AASHTO M288.
- The most consistent state specifications refer to the current AASHTO M288 specification.
- Some of the specifications that do not refer to AASHTO M288 still specify reasonable material properties for geosynthetics.
- The inconsistency of the state specifications makes it difficult for material manufacturers to supply proper materials. There are state specifications that no fabric could meet. There are also state specifications that do not appear to be reasonable for the specified application.
- There are numerous state geotextile material specifications that are up to date; these were utilized as a model for updating ADOT's specification.
- The ADOT installation specifications appear to be among the best and most comprehensive compared to the other state geosynthetic installation specifications.

Recommendation

- Use the information gathered in the survey to update ADOT's specifications and practices for geosynthetics.

REVIEW OF ADOT GEOSYNTHETIC SPECIFICATIONS

Current ADOT geosynthetic specifications, stored specifications, special provisions, and test methods were reviewed. The ADOT information was compared with similar information gathered from the survey. The ADOT information was also compared with industry and federal agency standard specifications and test methods. Sources included:

- AASHTO.
- American Society for Testing and Materials (ASTM).
- FHWA.

Findings

- Many ADOT specifications are not up to date with current industry standards and practices.
- ADOT specifications for geotextiles are not up to date with AASHTO M288. Values specified and test methods need to be updated.
- Many state specifications follow AASHTO M288 for most properties, but specify permittivity and AOS values that meet their state soil conditions.
- ADOT does not currently have a specification for stabilization geotextile.
- The ADOT specification for geogrid does not allow for newer, alternative types of geogrid such as triaxial geogrid.
- ADOT has a stored specification for geomembrane.

Recommendations

- Update ADOT geotextile specifications in accordance with AASHTO M288.
- Maintain ADOT-defined values for permittivity and AOS to accommodate Arizona soil conditions.
- Add a specification for stabilization geotextile in accordance with AASHTO M288.
- Update the ADOT specification for geogrid to a Type II Biaxial Geogrid, which is a non-proprietary type of geogrid sold by multiple manufacturers.
- Add a specification for triaxial or alternate geogrid types.
- Update the stored specification for geomembrane, and incorporate it into the standard specifications.

DESIGN GUIDELINES FOR BASE/SUBBASE REINFORCEMENT

The development of design guidelines was accomplished through two tasks. The first was to review existing ADOT design guidelines and compare them to other available industry design methods. The second was to review performance-related studies for geosynthetics to investigate the practical application of the design theories and methodologies.

Findings

Design Methods

- ADOT has been using geogrid for base/subbase reinforcement, but the design procedure is not fully documented.
- Several design methods have been developed for base/subbase reinforcement. However, the design methods are highly dependent on the specific design conditions that were used to develop them and cannot necessarily be widely applied to other design conditions.
- ADOT's existing design procedure for geosynthetics appears to be comparable to other design methods available in terms of its effect on reducing the pavement section thickness when geosynthetics are used.

Performance-Related Studies

- Performance-related studies do not indicate a clear and quantifiable benefit for using geosynthetics for base/subbase reinforcement. However, ADOT has been using geogrid for pavement reinforcement and has experienced satisfactory results with the existing ADOT design procedure.
- The review of field studies shows that the benefits and results realized in the studies are dependent on conditions, materials, and design configurations tested. This suggests that results of field studies are not widely applicable for design.

Recommendations

- Fully document the ADOT design procedure for using geogrid for base/subbase reinforcement.
- Add guidelines regarding the use of geotextile for separation in conjunction with geogrid for base/subbase reinforcement, based on the gradation of the subgrade.
- Consider adopting the recommended design guidelines are shown in Appendix Q.

DESIGN GUIDELINES FOR SUBGRADE STABILIZATION

Design guidelines for subgrade stabilization were developed through two tasks. The first was to review available design methods for subgrade stabilization. The second was to review performance-related studies for subgrade stabilization to determine whether the design methods were validated.

Findings

Design Methods

- Several design methods have been developed for subgrade stabilization.
- The design method developed for the USFS has been utilized by FHWA as well as the USACE and the US Army and Air Force. The method has been modified over the years, based on field experience and testing, to account for different types of geotextiles and geogrid. This design method is based on soil properties that can be easily measured in the field using standard test methods and design charts that have been developed for different vehicle types. This design method can be used for geotextiles and for geogrid.

Performance-Related Studies

- The use of a geosynthetic material may have many benefits. These benefits include the potential to extend the service life of pavement, improve ride quality, increase structural capacity, and improve cracking resistance.
- Any type of geosynthetic can provide a benefit. However, a non-woven geosynthetic may provide less benefit than a geogrid.
- The benefit associated with the use of a geosynthetic increases as the rut depth increases.

Recommendations

- Adopt design guidelines for using geosynthetics for subgrade stabilization based on the USFS design method.
- Consider adopting the recommended design guidelines are shown in Appendix R.

COST COMPARISONS

The cost comparison focused exclusively on construction costs (i.e., installed materials). There may be a long-term performance difference between pavements with and without geosynthetics; however, there are insufficient data in the literature to arrive at a conclusion at this time. Therefore, the cost analysis presented in this study does not factor in potential life-cycle cost savings of using geosynthetics in the pavement section.

Findings

Base Reinforcement

- In the base reinforcement analysis, the construction cost of pavement sections using geogrids and geotextiles was calculated and compared with the construction cost of pavement sections that did not use these materials.

- It is possible that there is a long-term performance difference between pavements using geosynthetics versus those without. However, there are insufficient data in the literature to support a conclusion on these alternatives.
- Construction cost comparisons for five road segments showed a clear benefit to using geosynthetics under the appropriate circumstances.
- The greatest construction cost savings from the use of geosynthetics for base reinforcement appears to occur when the R-Value is below 20.

Subgrade Stabilization

- The subgrade stabilization analysis calculated and compared the construction cost of subgrade stabilization for five different geosynthetic material alternatives.
- It is possible that there is a long-term performance difference between pavements using geosynthetics versus those without. However, there are insufficient data in the literature to support a conclusion on these alternatives.
- There is a clear construction cost savings to using geosynthetics under the appropriate circumstances.
- The greatest construction cost savings from the use of geosynthetics for subgrade stabilization appears to be in locations where the costs of AB Class 2 and excavation are highest.

DRAFT SPECIFICATIONS

Draft ADOT specifications for geotextile and geogrid products were developed and documented. These specifications were based on the surveys, research, evaluations, and design guidelines developed through this project. A review of the associated ADOT installation specifications for geosynthetics was also conducted.

A survey was conducted to obtain feedback from the geosynthetics industry on the draft specifications and draft design guidelines developed through this project. Three industry groups were selected to review the draft specifications and draft design guidelines:

- The Geosynthetics Materials Association (GMA).
- The American Society of Civil Engineers (ASCE) Geo-Institute (G-I).
- The North American Geosynthetics Society (NAGS), also known as the International Geosynthetics Society North America Chapter (IGSNA).

Findings

- The ADOT installation specifications for geosynthetics need to be updated in accordance with AASHTO M288 and other industry standards. Recommended changes are identified in detail in Chapter 7.
- The industry survey comments suggested a few relatively minor changes to the draft specifications. The survey comments are documented in Appendix T.

Recommendations

- Update the ADOT specifications for geosynthetics as discussed in Chapters 3 and 7 and shown in Appendix U.
- Add a specification for triaxial geogrid or alternative geogrid materials as shown in Appendix V.
- Update the ADOT specification for geomembrane as shown in Appendix W, and incorporate it into the standard specifications.

CONCLUSION

The project team comprehensively reviewed ADOT specifications and design procedures with respect to current industry standards for using geosynthetics for pavement design. Updated specifications and design guidelines were drafted and are presented in this report. The draft specifications and design guidelines were reviewed by industry experts and were revised according to their feedback and the direction of the project TAC.

Opportunities for Future Research

- Construct test sections at several locations on subgrade soils with an R-Value of 20 or less to determine the long-term performance of the recommended pavement sections with geotextile and geogrid. These pavement sections should be compared to pavement sections without geotextile and geogrid for at least a 10-year period, monitoring pavement section performance and performing tests such as falling weight deflectometer tests, which are used to evaluate the strength of the pavement section in place, at least every two years.
- If there are already pavement sections where geotextile and geogrid have been utilized, these pavement sections should be identified and evaluated in a similar manner. This is a possible future research area that can be utilized to help define the long-term benefit of the use of geogrid and geotextile together in pavement sections.

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