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GSI White Paper #40

Status of Pavement Design Methods Used by U. S. DOTs and Inclusion of Geosynthetics Therein

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1. Background and Overview

The amount of paved and unpaved roads in the world is enormous by anyone's standard. Shown in the following table is the situation in the U. S. and several selected countries. Here it is seen that percent of paved to unpaved roads varies greatly by country; ranging from 21% in South Africa, to 88% in China. While the U.S. is ranked highest for the size of its roadway system, there are many countries who have a higher percentage of paved roads. With only 65% of roads paved in the U. S., ASCE's infrastructure report card giving U. S. roads a "D" grade seems to be appropriate.

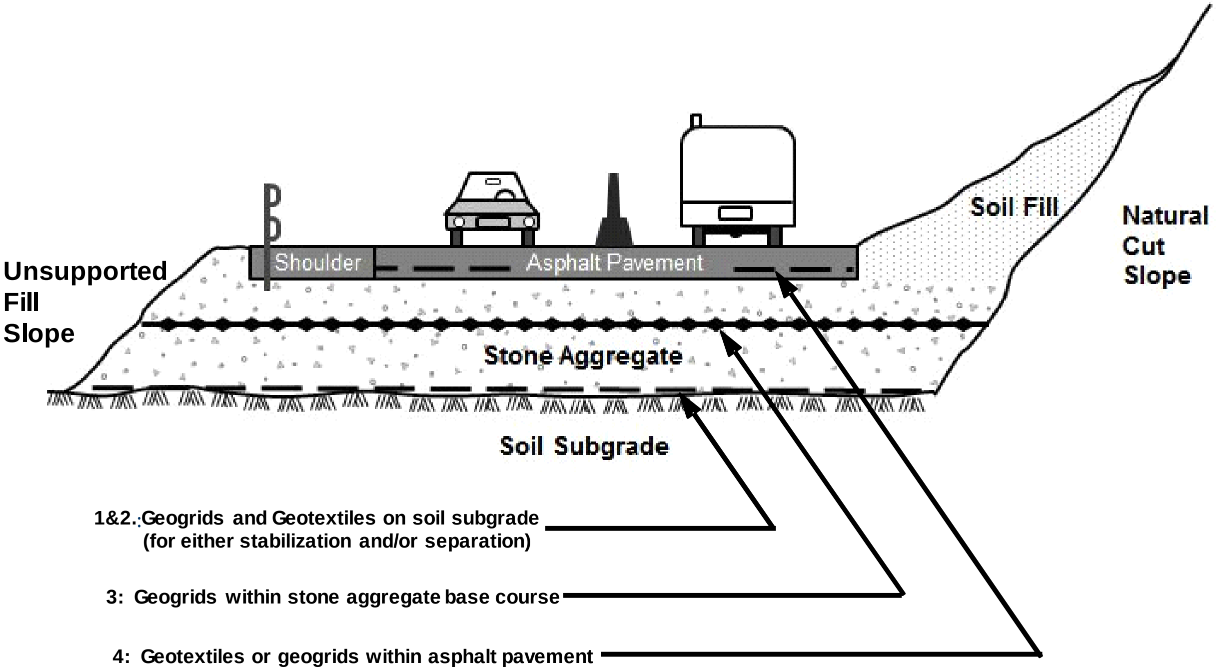
Status of Worldwide Paved and Unpaved Pavements in Selected Countries
(ref. The World Factbook – Central Intelligence Agency)

Country	**Paved**		**Unpaved**	
	km (x 1,000)	mi (x 1,000)	km (x 1,000)	mi (x 1,000)
USA	4305	2675	2282	1418
China	4046	2514	531	330
Japan	993	617	226	140
Russia	927	576	355	221
Canada	415	258	616	389
Mexico	378	234	137	85
South Africa	159	98	588	365

With ever increasing world populations and industrialization, the amounts will surely grow going forward. It is likely that new roads will be constructed and many unpaved roads will be paved. As such, for both future and existing roads, we feel that geosynthetics (mainly geotextiles and geogrids) will play a more significant role than is the current situation. The resulting improvements offered by geosynthetics come about by two major features afforded by such inclusions;

- improved lifetime and/or performance, or
- thinner and therefore more economic cross sections.

In light of the various possibilities that geosynthetics can provide, there are at least four pavement applications which have been developed to-date in whole or in part. See the following sketch (taken from a regularly given GSI Webinar) for the various possibilities.



For this White Paper we focus on geogrids within the stone gravel base course, or geogrids and/or geotextiles directly on the soil subgrade. Thus, reinforcement (also called stabilization) of the gravel base course is the major function provided by the geosynthetic material. In this regard, we are inferring the following characteristics:

- Asphalt paved roadway surfaces
- Gravel base courses of varying thickness

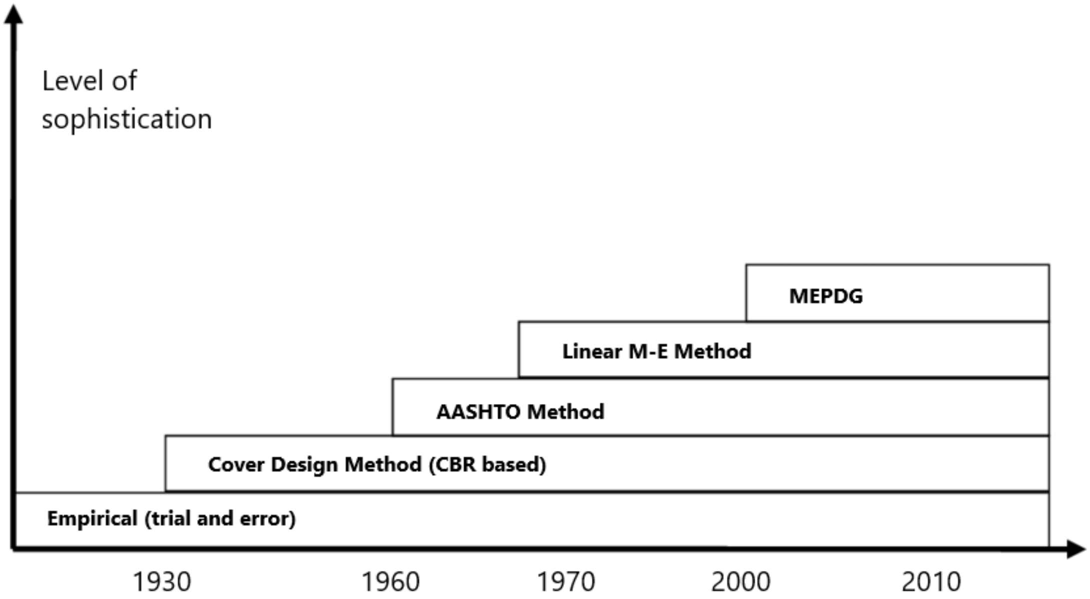
- Generally no additional subbase course layer
- Firm soil subgrades, e.g., CBR ≥ 8
- Potential use of geogrids within the gravel base course, or geogrids and/or geotextiles directly on the soil subgrade

In the context of openness, it should be mentioned that the purpose of this White Paper is to assess the state-of-the-practice *in the use of geosynthetics* in roadway cross sections by state DOTs in the U. S. Thus, the survey sent to pavement design personnel and results to follow are in two discrete sets of questions.

- Current status of U.S. DOTs design methods <u>without</u> geosynthetics.
- Current use by the U.S. DOTs of geosynthetics in their selected design method(s).

2. Pavement Design Methods

Reck (2009) nicely captures the progression of pavement design methods used over time in the following figure.



Evolution of pavement design methods (Reck 2009).

At this point in time, the **empirical (trial and error) method** is completely inappropriate, as is the **cover design method** which was primarily based on the CBR of the subgrade soil. On the other hand, the **AASHTO road tests** of 1958-'60 eventually generated a deterministic design method published in 1972. It was updated in 1986 and 1993. It is fundamentally based on Westergaard's and Burmeister's[*], "beams on elastic foundation" theories, and then juxtaposes the following field performance and related design criteria to arrive at the two basic design equations.

- Field test location in Ottawa, Illinois
- Climatic details at the time of the test
- Time of construction
- Traffic application
- Test conditions of six 2-lane loops
- Traffic with fixed load magnitudes on each test loop
- Performance measurements – roughness and visual distress, deflection, strains, and Present Serviceability Index (PSI)
- Pavement surface characteristics

The resulting design formulation is given as Equation 1. It is solved by nomograph for the unknown structural number (SN) …

$$log W_{18} = Z_R \times S_O + 9.36\, log(SN+1) - 0.2 + \frac{log\frac{\Delta PSI}{2.7}}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log M_R - 8.07 \quad \text{Eq. 1}$$

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[*] Bob K's master's degree advisor at Columbia University in the late 1950's.

where

$$\left.\begin{array}{ll} W_{18} & = \text{number of ESALs over design life} \\ Z_R & = \text{standard reliability level} \\ S_o & = \text{standard deviation} \\ \Delta_{PSI} & = \text{allowable loss in serviceability} \\ M_R & = \text{resilient modulus of subgrade} \end{array}\right\} \text{tables are available}$$

The SN-value that is obtained is then distributed to each layer's properties so as to determine the unknown thicknesses (d).

$$SN = (a \times d)_{asphalt} + (a \times d \times m)_{base\ course} \qquad \text{Eq. 2}$$

where

$$\left.\begin{array}{l} a = \text{coef. of relative strength} \\ m = \text{modifier for moisture conditions} \end{array}\right\} \text{tables are available}$$

d = thickness of each layer which is the "unknown".

From a geosynthetics perspective, the intrinsic value of this AASHTO method is its adaptability to the inclusion of geogrid or geotextile inclusion within or under the stone base course using either a base course reduction (BCR) factor or a traffic benefit ratio (TBR). Examples of the process follow, however, it must be recognized that the above values must be for a specific geosynthetic material.

Using a base course reduction (BCR) factor:

1. Obtain "SN" from Equation 1
2. Obtain BCR factor for a given geotextile or geogrid (say, for example, 15%)
3. Calculate unreinforced base course thickness (d_{ur}) from Equations 1 and 2 (for example, 12.0 in.)

4. Calculate the reinforced base course thickness (d_r) using the above assumed values.

$$BCR = \frac{d_{ur} - d_r}{d_{ur}} \qquad \text{Example;} \quad 0.15 = \frac{12 - d_r}{12}$$

$$= 0.15\ (assumed) \qquad \therefore d_r = 10.8\ in.$$

<u>Using the traffic benefit ratio (TBR) value:</u>

1. Obtain TBR for a given GT or GG (say, for example, 5.0)
2. Assume the number of EASLs of wheel load of $W_{18\text{-}ur}$ to be 5×10^6.
3. Calculate $W_{18\text{-}r}$ from TBR = $W_{18\text{-}r}/W_{18\text{-}ur}$ Example; $5 = \frac{W_{18-r}}{5 \times 10^6}$

$$\therefore W_{18-r} = 25 \times 10^6 EASLs$$

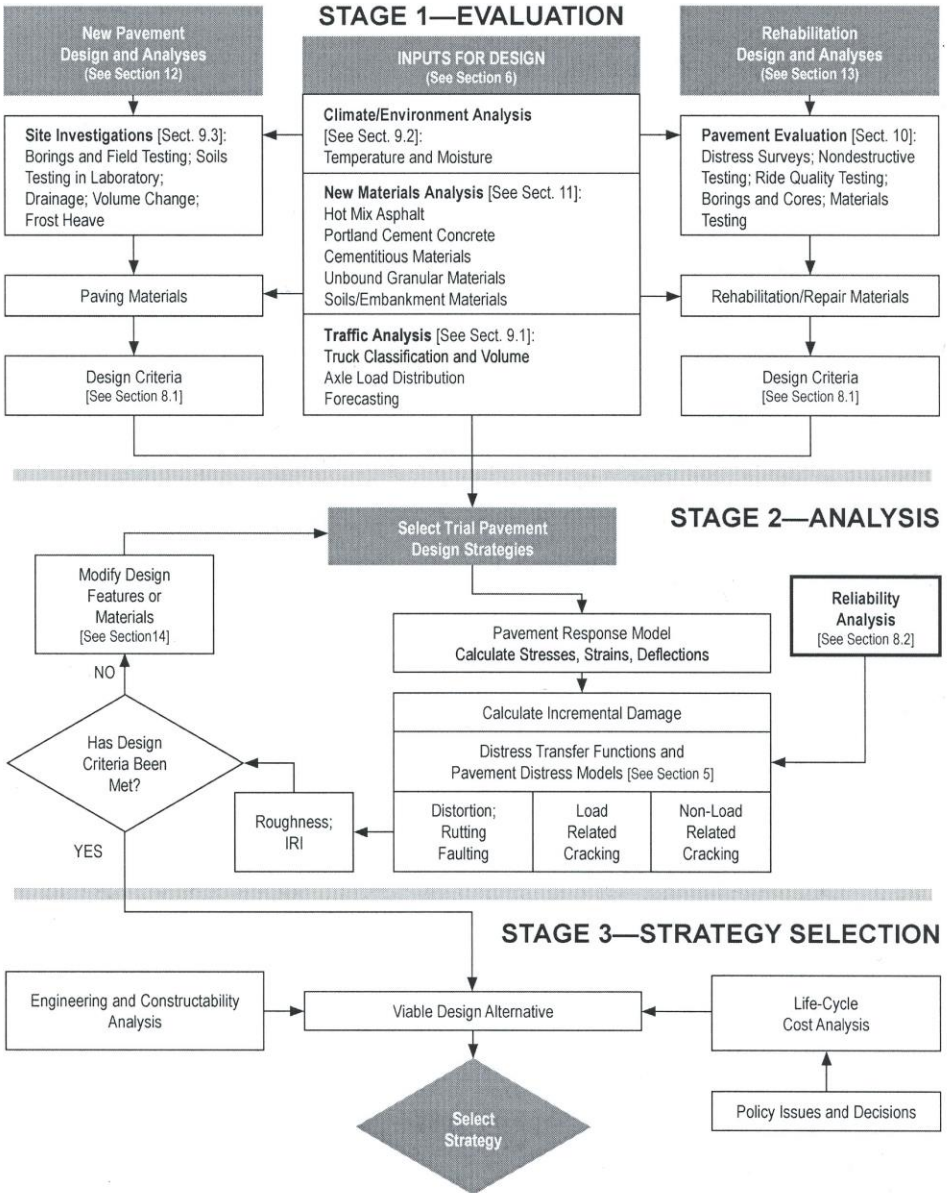
The **Mechanistic-Empirical Pavement Design Guide (MEPDG)** builds on the original Linear ME design. At the outset, it is important to recognize that the MEPDG predicts multiple performance indicators and a direct tie between materials, structural design, construction, climate, traffic, and pavement management system. *The outputs are pavement distress and smoothness, not layer thickness.* The designer first considers site conditions (i.e., traffic, climate, subgrade, existing pavement condition for rehabilitation) in proposing a trial design for a new pavement or rehabilitation strategy. The trial design is then evaluated for adequacy against user input, performance criteria, and reliability values through the prediction of distresses and smoothness. If the design does not meet the desired performance criteria at the specified reliability, it is revised and the evaluation process repeated as necessary. Thus, the designer is fully involved in the design process and has the flexibility to consider different design features and materials to satisfy the performance criterion for the site conditions. Details are shown in the following flow chart. Even further there are three levels of possible use:

Level-1. Detailed level – where most of the input variables are obtained by measurement.

Level-2. Intermediate level – where many of the variables are default values or dummy variables.

Level-3. Practical/Default level – Where most of the inputs are default values and only the basic variables are actually measured.

In the mechanistic empirical (ME) model, the contribution of a thin layer such as a geosynthetic can be incorporated as an equivalent resilient modulus and Poisson's ratio. Yet, in the design processes, calibration of the equivalent damage model in terms of subgrade rutting has not provided similar results for thin and thick asphalt geosynthetic-reinforced flexible pavements. Specifically, in thin asphalt pavements the geosynthetic contribution has been incorporated into the properties of the base course layer, whereas in thick asphalt pavements it has been simulated as an equivalent delay in the onset of fatigue cracking (when compared to the onset of fatigue cracking of an unreinforced pavement section). Consequently, the benefits of geosynthetics have not been consistently defined using the Mechanistic-Design (ME) design process.



Conceptual Flow Chart of the Three-Stage Design/Analysis Process for the MEPDG

3. Status of Pavement Design Methods by U. S. DOTs

The Geosynthetic Institute (GSI) recently sent out a short survey to all fifty U. S. DOTs as to which of the previously described design methods are being used in their state for pavement design. The usage options given were the following:

- Their own method based on past experience.
- AASHTO method (either 1972, 1986 or 1993 versions).

- Mechanistic-Empirical (ME) method (either Linear ME or MEPDG).
- Other method, e.g., other state or vendor designs.

The results were somewhat difficult to obtain since pavement design in a particular state can be located within many different departments, e.g., structural, geotechnical, materials or a designated pavement division. Thus, identifying a specific agency individual knowledgeable in the design process was sometimes difficult. When surveys were simply not returned (about 40%), the Website of the remaining states was used for the requisite information. The responses of all fifty states are given in Table 1. Please note that some states use more than one design method so there are a total of 80 (rather than 50) responses. Here it is seen that…

- 17 states use their own method based on past experience
- 40 states use the AASHTO design method (most states use the 1993 version)
- 18 states use the Mechanistic-Empirical method (either Linear or MEPDG)
- 5 states use another method other than those listed above

Table 1 - Various U. S. State DOT Pavement Design Methods
(ref. GSI White Paper #40, November 30, 2018)

State	**Own Method**	**AASHTO Method**	**ME PDG Method**	**Other**	**State**	**Own Method**	**AASHTO Method**	**ME PDG Method**	**Other**
Alabama	x				**Montana**		x93		
Alaska	x				**Nebraska**	x	x		
Arizona		x93		SODA	**Nevada**	x			
Arkansas		x			**N Hampshire**		x		
California	x	x			**New Jersey**		x93	x	
Colorado		x	x		**New Mexico**	x	x93		
Connecticut		x93		PaveXPress	**New York**		x93		
Delaware		x93			**N Carolina**		x		
Florida	x	x86			**N Dakota**	x	x93		
Georgia		x	x		**Ohio**		x93	x	
Hawaii		x			**Oklahoma**		x	x	
Idaho		x	x	Winflex 2000	**Oregon**		x		
Illinois	x	x			**Pennsylvania**		x	x	
Indiana	x		x		**Rhode Island**		x		
Iowa		x93			**S Carolina**	x	x72	x	
Kansas		x93	x		**S Dakota**		x93		
Kentucky			x		**Tennessee**	x	x93		
Louisiana		x93	x		**Texas**	x			TXCRCP, SPS
Maine		x	x		**Utah**	x		x	
Maryland		x93	x		**Vermont**		x93		
Massachusetts		x			**Virginia**	x	x	x	
Michigan		x	x		**Washington**		x93		
Minnesota	x			MN Pave	**W Virginia**		x93		
Mississippi	x				**Wisconsin**		x72		
Missouri			x		**Wyoming**		x		

4. Status of Geosynthetic Usage in Pavement Design by U. S. DOTs

The second part of the survey had to do with (i) what type of geosynthetics were being used in the state's pavement design, (ii) the intended purpose of such inclusions, and (iii) the location within the pavement cross section other than the base course. The specific options given were the following;

- type of geosynthetic material,
- purpose for using the geosynthetic and
- the location of the geosynthetic within the total pavement section.

The responses are given in Table 2. Here it is seen that…

- Almost all states use geotextiles or geogrids while twenty-five states use both. Only four states use neither.
- The purpose of using such reinforcement is almost always for improved performance (assumed to be longer lifetime or less rutting). Only three states mentioned reduced gravel base course thickness.
- The location of geosynthetics used resulted in very varied answers, i.e.,
    - eight used geosynthetics within the bituminous pavement itself for the prevention of reflective cracking,
    - fourteen used geotextiles as separators between the bottom of the gravel and the soil subgrade,
    - nine used geotextiles or geogrids within the soil subgrade for reinforcement, and
    - eight used geosynthetics for still other purposes, e.g., seismic reinforcement, wicking, filtration, load distribution and undercutting.

Table 2 - Use of Geosynthetics in Pavement Design by U. S. State DOTs
(ref. GSI White Paper #40, November 30, 2018)

State	**Types of Geosynthetic**			**Purpose**		**Location Other than Base Course**			
	GT	**GG**	**None**	**Performance**	**Reduce Thickness**	**Asphalt**	**Separation**	**Subgrade**	**Other**
Alabama	x	x		x					
Alaska	x	x		x				x	wicking
Arizona	x	x		x					filters
Arkansas	x	x						x	seismic
California	x	x			x				
Colorado	x	x		x					
Connecticut	x			x		x			
Delaware			x						
Florida	x	x		x					
Georgia	x	x						x	
Hawaii	x					x	x		
Idaho	x	x		x	x				seismic
Illinois	x			x					
Indiana	x	x		x			x		distribute load
Iowa		x		x					
Kansas	x	x		x					
Kentucky	x	x		x					
Louisiana	x	x		x					
Maine	x			x		x			thawing
Maryland	x			x			x	x	
Massachusetts	x			x			x		
Michigan	x	x		x		x			
Minnesota	x	x		x				x	
Mississippi	x			x		x	x		
Missouri	x						x		seismic
Montana	x			x			x		

Table 2 - (cont.)

State	Types of Geosynthetic			Purpose		Location Other than Base Course			
	GT	GG	None	Performance	Reduce Thickness	Asphalt	Separation	Subgrade	Other
Nebraska			x						
Nevada	x	x		x		x			
N Hampshire	x								
New Jersey	x			x					
New Mexico	x	x		x		x	x	x	
New York			x						
N Carolina	x			x				x	
N Dakota	x	x		x			x		
Ohio	x	x		x					
Oklahoma	x			x			x	x	
Oregon	x	x		x					
Pennsylvania	x			x			x		
Rhode Island	x			x					
S Carolina	x	x		x		x	x	x	
S Dakota	x	x		x					
Tennessee			x						
Texas	x	x			x		x		
Utah	x	x		x					
Vermont	x			x					
Virginia	x			x			x		undercut
Washington	x	x							
W Virginia		x		x					
Wisconsin		x		x					
Wyoming	x			x					

5. Summary

The shear size of the paved and unpaved roads in the U. S. and the world is huge and ever increasing. As such, highway departments play the leading role insofar as the design of site-specific cross sections are concerned. In the U.S. this is led by individual state DOTs or by their collective organization, the American Association of State Highway and Transportation Officials (AASHTO). Clearly, many research projects and field investigations have been conducted since transportation began in the modern era. Indeed, many approaches toward such designs are available. The more recent methods were reviewed herein. This being the situation, we at GSI felt that insight into the current status of state DOTs was warranted with respect to two basic issues. These are, (i) inquiring into the specific design methodologies currently in use by the state department pavement designers, and (ii) inquiring into the current use of geosynthetics (mainly geotextiles and geogrids) within the aggregate base course of such roadway cross sections. Approximately, 60% of the state DOTs answered our survey directly and, for the remainder, we relied on the individual states' websites. It should be mentioned that some states use more than one design method, as well as more than one type of geosynthetic so that the totals are greater than fifty. The results to our two basic questions are as follows:

Regarding the design method used (see Table 1), the AASHTO method is by far the most widespread. Forty states used the method, of which most use the recent version which was published in 1993. This is felt to be fortunate from a geosynthetic perspective since geotextile or geogrid inclusions within or beneath the gravel base course is readily accomplished using either thickness reduction or improved performance objectives. The latter being longer lifetime and/or better reliability. Furthermore, seventeen states use their own design method, and, by virtue of the next question they use geosynthetics quite regularly. Eighteen states use the mechanistic-empirical (M-E) method which, as stated earlier, does not seem to have an easy access methodology for inclusion of geosynthetics. Five states use a different method altogether which may be a vendor's method, although the question was not asked directly. Lastly, the totals of the above come to eighty indicating that many of the states use more than a single design method.

Regarding the use of geosynthetics in the states' pavement designs, all but four states use geotextiles or geogrids within or directly beneath the gravel base course. As seen in Table 2, geotextiles are slightly more commonly used than geogrids. Interestingly, the purpose of the geosynthetic inclusion is almost always improved performance. It is assumed that this comes about by either improved durability or better rideability. Only three states used the inclusion to reduce the thickness of the gravel base course. Lastly, other uses of geosynthetics in the pavement cross section was solicited. These results were as follows:

- Prevention of reflective cracking – eight states
- Separators between the base course and soil subgrade – fourteen states
- Reinforcement of weak soil subgrades – nine states
- Other purposes – eight states

Within this last group, we feel that many states use geotextiles as underdrain filters, however, our survey was not sufficiently explicit in this regard.

Acknowledgements

Sincere appreciation is extended to the State DOT pavement design engineers for responding to our survey. They have been sent the results as promised. As always, we thank the members of the Geosynthetic Institute for their ongoing support of our various activities. They are listed, with their websites, on our home page at <www/geosynthetic-institute.org/memberlist.htm>.

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