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TESTING PROCEDURES, SPECIFICATIONS, AND APPLICATIONS FOR GEOFABRICS IN HIGHWAY PAVEMENTS

by

Tom Scullion

Stephen M. Lux

Clyde N. Holland

Research Report 414-1F
Fabrics Under Base Courses
Research Study Number 2-8-83-414

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

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DISCLAIMER

The report is not intended to constitute a standard, specification or regulation, and does not necessarily represent the views or policy of the FHWA or Texas Department of Highways and Public Transportation.

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1. INTRODUCTION

The use of geofabrics* in highway application has developed very rapidly. Ten years ago geofabrics were confined to experimental projects, however recently it was found (1) that

(A) 30 DOT's regularly use geotextiles (permeable geofabrics) in drainage applications

(B) 18 DOT's regularly use geotextiles to protect untreated subgrades to separate granular base roadbed materials

(C) 30 DOT's regularly use geotextiles as silt fences

Growth of geofabrics usage has not been confined to the pavement industry. Recently (2) the Southern Pacific Railroad reported that it has installed 1000 miles of geotextile beneath track ballast mostly in the Texas, Louisiana area. This area is well known for its poor soil condition and high water table problems. For this application, a thick non-woven geotextile was chosen to minimize the infiltration of soft clay particles into the ballast and to improve in-plane drainage.

The Texas Department of Highways and Public Transportation has recently constructed several projects using geofabrics. District 1 (Paris), District 19 (Atlanta), District 20 (Beaumont), and others have all installed geofabric sections. The District which has been most active is District 15 in San Antonio, here geomembrane (impermeable geofabrics) applications have been aimed at minimizing

*Geofabric is the ASTM approved term. It replaces terms such as fabric, engineering fabric, etc. See Section 2 for further discussion.

the damage done to pavements by expansive soils. The District has reported (3) good success with vertical moisture barriers installed at the edge of a recently overlaid section of Interstate highway. These geomembranes have stabilized the moisture content of the pavement's subgrade and hence minimized the movements due to the active clay (32). This is clearly shown in pavement roughness measurements taken on the geomembrane treated and control sections. The District has also installed experimental sections on General McMullen Drive in which a geomembrane has been laid between the subgrade and base course to protect the moisture sensitive clay subgrade. Monitoring of this experiment (33) has indicated that the geomembrane section has less surface cracking than the control section.

It does appear that there are several applications in which geofabrics may prove cost effective. However, there are several problems which must be overcome before the potential of geofabrics can be fully evaluated. First and foremost there are no approved geofabric tests or geofabric specifications. An engineer wishing to use geofabrics in a specific application is faced with several types of geofabric to choose from and a bewildering list of manufacturer supplied test results. Furthermore, there is a general lack of understanding of the fundamental behavior of geofabrics in pavements and this leads to uncertainty over which test result is important in predicting long term performance.

The purpose of this report is as follows:

1. To summarize the literature on testing and specification of

geofabrics for use in drainage, separation, reinforcement, silt fencing applications, and for use as impermeable barriers.

2. Based on this survey, to recommend a testing program and specifications.
3. To recommend areas in which the Department can expect the cost-effective benefits from geofabrics.
4. To summarize the theory which best explains the function of the geofabric in each application (e.g. what function does the geofabric perform in drainage?). An effective testing program can only be defined once the geofabric function is understood.

As stated, the recommendations in this report are based solely on the results of a literature survey. However, throughout this review every effort has been made to promote the results which are based on laboratory and field test results. In the course of the survey an extensive library of geofabric literature has been assembled and the sources found most valuable are listed below;

1. The Federal Highway Administration (including (4,5))
2. The Second International Conference on Geotextiles (6)
3. The Corps of Engineers
4. Textbooks on Geofabric Applications (7,8)
5. The Geofabric Manufacturers
6. Other States DOT
7. ASTM

The ASTM D18.19 subcommittee on geofabrics has been studying this specifications problem since 1977 (9), and as of March 1984 it has not produced any definitive guidelines. The ASTM first attempted to adopt tests and specifications from the textile industry and ran into problems of testing applicability and completeness. For instance, how can a test designed to measure wear on carpets be used for highway application? Furthermore they had no approved permeability tests which are clearly required when considering geotextiles for drainage applications. In recent years their efforts have been directed towards more realistic engineering based testing methods, and it is expected that by late-1984 the ASTM will publish some tentative recommendations.

The best reference found in this search was an FHWA report (4) based on work recently completed at Oregon State University. The recommendations of this FHWA report are used extensively herein.

Outline of Report

In the next section of this report, the types of geofabrics available will be discussed. This is intended as an introduction for those unfamiliar with the geofabric industry. The types of manufacturing and finishing processes will be presented, and comparison of the engineering properties of woven versus nonwoven will be given. A list of geofabrics available in Texas is presented, and information such as typical strengths, permeabilities, and costs are included. This table is not a complete listing of all available geofabrics (this would be very difficult as manufacturers are frequently upgrading their product lines), rather the table is intended to give the reader an overview of the range of geofabrics available and their cost.

The main body of the report is covered in sections 3 through 7 where the filtration, separation, reinforcement, silt fencing, and geomembrane (impermeable barrier) applications are discussed in detail. Each of these sections follows essentially the same format. First, the function of the geofabric is explained and then the available laboratory and field results are summarized. Where possible, each of these sections gives guidelines for testing, specifying, and selecting a geofabric for that application.

Section 8 presents a summary of recommendations. These include

a) A list of testing procedures which are considered necessary when testing and specifying geofabrics.

b) A tentative list of geofabric specifications.

c) A list of applications which appear to offer cost-effective applications to the Department. It is recommended that those applications not currently being studied, be included in future experimental projects.

In Appendix A, a summary is given of the geofabric experimental projects currently installed within Texas. Performance data, including Mays Ride and Dynaflect results have been included.

In Appendix B, an analytical approach to studying the strengthening effects of geofabrics on pavements is presented. Considerations such as the fabric interface and interpretation of the analytical solutions are presented here. Recommendations for future analyses have also been included in Appendix B.

2. TYPES OF GEOFABRICS

The ASTM definition of geofabrics is "any permeable or impermeable textile used with foundation, soil, rock, earth, or any other geotechnical engineering related material as an integral part of a man-made product, structure, or system." A basic classification system for highway geofabrics is shown below in Figure 2.1, the permeable geofabrics are known as geotextiles, and the impermeable geofabrics are called geomembranes. To avoid confusion, this nomenclature will be used throughout this report.

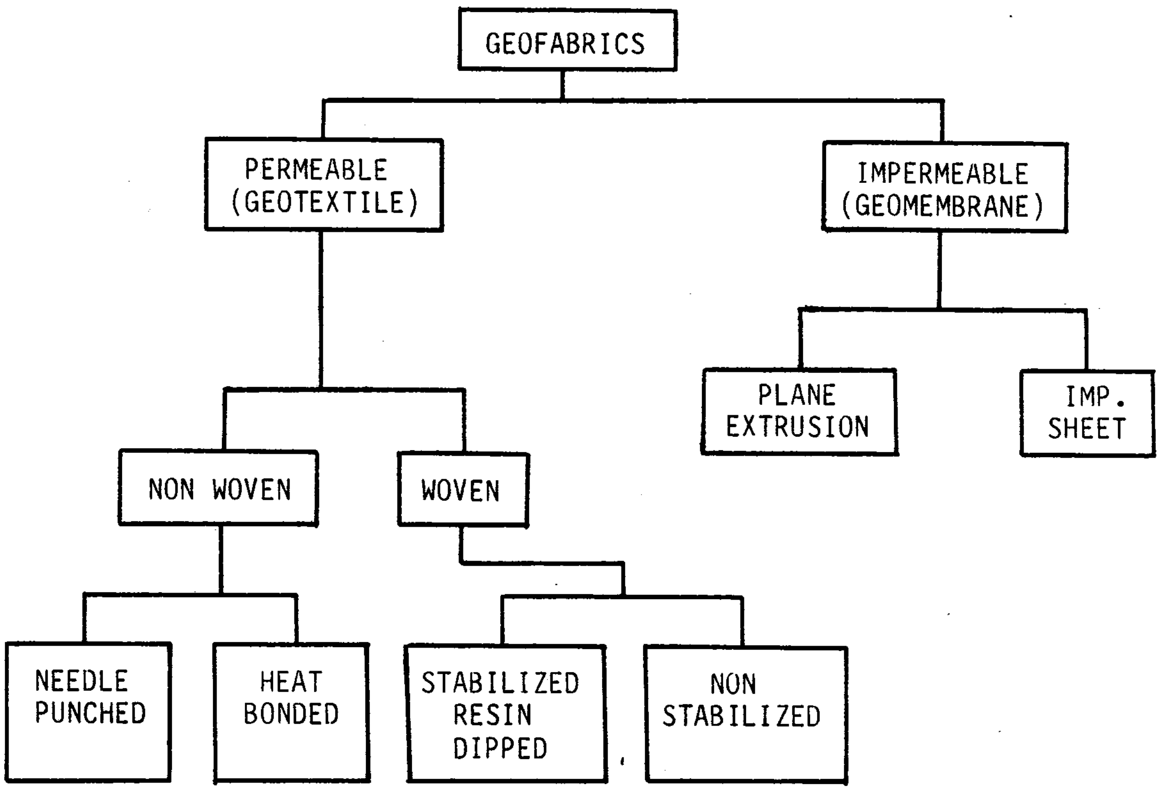


Figure 2.1 Basic Classification System for Highway Geofabrics (after (7))

In the current rapidly expanding market, new manufacturing processes are continually being developed. A classification system which included all possible manufacturing processes would be extremely complex and in continual need of updating. Therefore it is felt that the proposed classification system in Figure 2.1 is a good introduction to the types of geofabrics available.

The first breakdown is between permeable (geotextiles) and impermeable (geomembranes) geofabrics. There are two basic types of geomembranes. In the first case there are sheets of extruded plastic material which are continuous and extruded as a single sheet. Secondly, there are woven/nonwoven geofabrics which have an impermeable sheet bonded to them.

As shown in Figure 2.1, the geotextiles are broken into woven and nonwoven. These are discussed in detail below.

Woven Geotextiles

The woven geotextile is made on a loom. The warp threads run down the length of the loom and are continually raised and lowered. The weft threads have to be thin and flexible as they are inserted between the warps from a shuttle. The strength of the woven geotextile is dependent upon a) the materials used, b) the "tightness" of the geotextile (number of threads per inch), and c) the finishing process (resin gluing or heat treatment).

Geotextiles may be woven from monofilaments which are single strands of extruded polymer. These are usually intermediate strength geotextiles. Geotextiles may also be woven of multifilament yarns.

These materials have intermediate to high strengths. They may be somewhat more expensive than the monofilament geotextiles, but the strongest of all materials are manufactured in this manner. Some geotextiles are made of ribbon filaments formed by slitting sheets or films of plastic to form slit film ribbons. The slit film woven geotextiles are usually lighter weight and weaker than the other woven geotextiles.

Nonwoven Geotextiles

Nonwoven geotextiles consist of mats of filaments orientated in a more or less random order and bonded together to form a coherent geotextiles. They are automatically manufactured and are relatively inexpensive. They are formed from fine extruded monofilaments. In some processes the filaments are continuous, in others they are chopped into short lengths (staple filaments). Continuous filament geotextiles tend to have the same mechanical properties in all directions.

Needle punched geotextiles are manufactured by passing a nonwoven fabric through a needle loom which has thousands of barbed needles which penetrate the fabric and mechanically interlock the fibers. This mechanical interlocking bonds the geotextile and contributes to the geotextiles' strength (35). The needle punched geotextiles are generally thicker than other nonwovens, are compressible, and are claimed to permit drainage through the plane of the geotextile.

The heat bonding process locks the fibers in place by bringing the outside surface of each fiber to the semi-liquid state by the application of heat. Once in the semi-liquid state, the fibers are pressed together and then cooled down. When the fibers return to the solid state, they are stuck together at each fiber to fiber contact point. The engineering properties of any nonwoven geotextile are greatly influenced by the finishing and bonding process.

Comparing Woven and Nonwoven Geotextiles

Strength Tests

Other factors equal, the nonwovens tend to be somewhat weaker and have considerably lower moduli than the woven geotextiles. This is shown below in Figure 2.2.

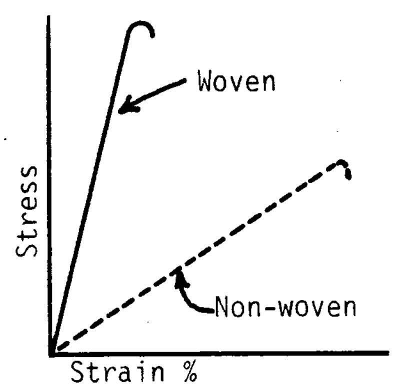


Figure 2.2 Stress vs. Strain Characteristics of Woven and Nonwoven

The higher strength of wovens is not automatically an advantage in all cases, since it is becoming common for modern specifications to recommend more extensible geotextiles particularly for use on soft ground. Furthermore, the strength of wovens is dependent upon the direction of testing (10), higher strengths have been found at 45^{o} to the warp and weft directions than along them.

Pore Size

The regular shape of the woven structure means that the holes in the geotextile are of a regular size and shape. They are virtually single size. On the other hand, the nonwovens, because of the random orientation of fibers, have a distribution of hole sizes. This comparison is illustrated in Figure 2.3.

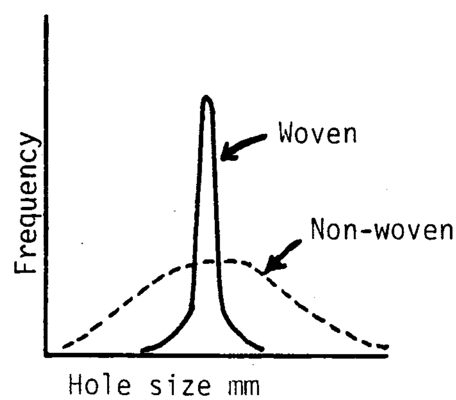


Figure 2.3 Hole Size Distribution of Woven and Nonwovens

The woven geotextile can therefore be described in terms of its Apparent Opening Size (AOS Test). This test, also known as "reverse sieving," is in the final stages of balloting by ASTM. It involves repeated sieving glass beads of known size, the Apparent Opening Size is defined as that bead size at which 5% or less by weight pass through the geotextile after 20 minutes sieving.

This test works well for woven fabrics which, as shown in Figure 2.3, have a reasonably uniform hole size, but its applicability to nonwovens is in some doubt because of their distribution of hole sizes. However, the AOS test is the only method available for measuring hole sizes in geofabrics at this time.

This hole size distribution has important implications when considering the clogging potential of geotextiles in drainage applications.

Typical Engineering Properties and Cost of Geofabrics Available in Texas

Tables 2.1 and 2.2 summarize the manufacturer supplied engineering properties and cost data as of July 1984. Table 2.1 illustrates the range of nonwoven geotextiles available in Texas. Table 2.2 presents the woven geotextiles. These tables are not a complete listing of all available geofabrics (this would be very difficult as manufacturers are frequently upgrading their product lines), rather the table is intended as an overview.

A word of warning concerning the listed engineering properties. It is extremely difficult to use these to compare geofabrics. The geofabrics section of ASTM has not finalized the laboratory testing procedures and there are differences in manufacturers test procedures.

Table 2.1. NONWOVEN GEOTEXTILES

Manufacturer & Trade Name	Application	Material[1] and Process[2]	Weight (oz/yd^2) ASTM D1910	Thickness mils ASTM D1777	Grab Tensile Strength ASTM D1682	Modulus (lbs) ASTM D1682	Trapezoidal Tear (lbs) ASTM D1117	% Elongation at Burst ASTM D1682	Price[*] \$/yd^2
Amoco Fabrics									
Propex 4545	Drainage	1B	4.5	45	90# min			50 min	0.65-0.43
4551		1B	6.0		125# min			50 min	0.80-0.60
4553		1B	8.0	75	150# min			50 min	0.95-0.75
4557	R.R. Stab.	1B	12.0	134	200# min			50 min	1.30-1.10
DuPont									
T-063	Impervious Support	1C-3	7.5	15.5	180	1150	54[3]	68	1.69
3341	Drainage	1C	3.4	13.0	125	1000	48[3]	96	0.67
3401	Multi-purpose	1C	4.0	15.0	135	1200	74[3]	62	0.76
3421	Multi-purpose	1C	4.2	15.5	142	990	75[3]	86	0.73
3601	Road Support	1C	6.0	18.0	207	2500	103[3]	63	1.11
Moechst Fibers									
Trevira									
1115	Multi-purpose	2A & B	4.5	85	130/110	--	50/45	85/95	0.53
1120	Multi-purpose	2A & B	6.0	100	175/155	--	65/60	85/95	0.80
Mirafi									
140N	Drainage	1 & 4 B, C	4.0	60	120	N/A	50	55	70-50
Phillips Fibers									
Supac									
4 NP	Multi-purpose	1, B, C	4.1	40	115		48	65	0.5125
4-1/2 NP	Multi-purpose	1, B, C	4.5	--	--		--	--	0.5875
5 NP	Multi-purpose	1, B, C	5.3	55	165		63	70	0.65

(1) Fiber Types
1 - Polypropylene
2 - Polyester
3 - Alathon EVA Impermeable Coating
4 - Other

(2) Process
A - Nonwoven, Spun bonded
B - Nonwoven, Mechanically bonded
C - Nonwoven, Thermal bonded
D - Woven, Slit Film

(3) ASTM D2263

* Price varies with quantity ordered. Prices as of July 1984.

Table 2.2. WOVEN GEOTEXTILES

Manufacturer & Trade Name	Application	Material[1] and Process[2]	Weight (oz/yd^2) ASTM D1910	Thickness mils ASTM D1777	Grab Tensile Strength ASTM D1682	Modulus (lbs) ASTM D1682	Trapezoidal Tear (lbs) ASTM D1117	% Elongation at Burst ASTM D1682	Price* $/yd^2
Amoco Fabrics									
Propex 2002	Stabilization	1D	4.5	--	200	--	75[3]	20	0.65-0.45
2006	Stabilization	1D	6.0	--	275	--	120[3]	20	0.80-0.60
Mirafi, Inc.									
500X	Stabilization	1D	4.0	23	200	115	115	30	0.50-0.70
600X	R. R. Stab.	1D	6.0	33	300	140	120	35	0.70-0.95
Phillips Fibers									
Supac									
4WS	Stabilization	1D	4.0	--	--	--	--	--	0.5125
5WS	Stabilization	1D	5.1	--	295	120	--	25	0.5875
6WS	Stabilization	1D	6.7	--	320	165	--	26	0.6500

(1) Fiber Types
- 1 - Polypropylene
- 2 - Polyester
- 3 - Alathon EVA Impermeable Coating
- 4 - Other

(2) Process
- A - Nonwoven, Spun bonded
- B - Nonwoven, Mechanically bonded
- C - Nonwoven, Thermal bonded
- D - Woven, Slit Film

(3) ASTM D2263

* Price varies with quantity ordered. Prices as of July 1984.

3. DRAINAGE AND FILTRATION

3.1 Introduction

Filtration for drainage purposes is the process of allowing water to pass out of a soil medium while preventing passage of fine soil particles. Good drainage is essential for long-lasting maintenance free pavements. When water is permitted to remain in the structural layers it greatly increases the rate of pavement deterioration (11). Although granular drains and filter criteria are well established, they are often costly and difficult to build and maintain.

Figure 3.1 shows several examples of longitudinal highway drains. Figure 3.1a illustrates a drain excavated on the uphill side of a roadbed. The depth of the drain depends on hydrostatic pressures and soil permeabilities. When the ground is nearly level, several drains may be required (Figure 3.1b).

Geotextiles can be used in subsurface drains as an alternative to graded granular drains. The geotextile eliminates the need for graded aggregate by triggering a self-filtering phenomenon in the in-situ soil. A typical subsurface drain incorporating a geotextile is illustrated in Figure 3.2.

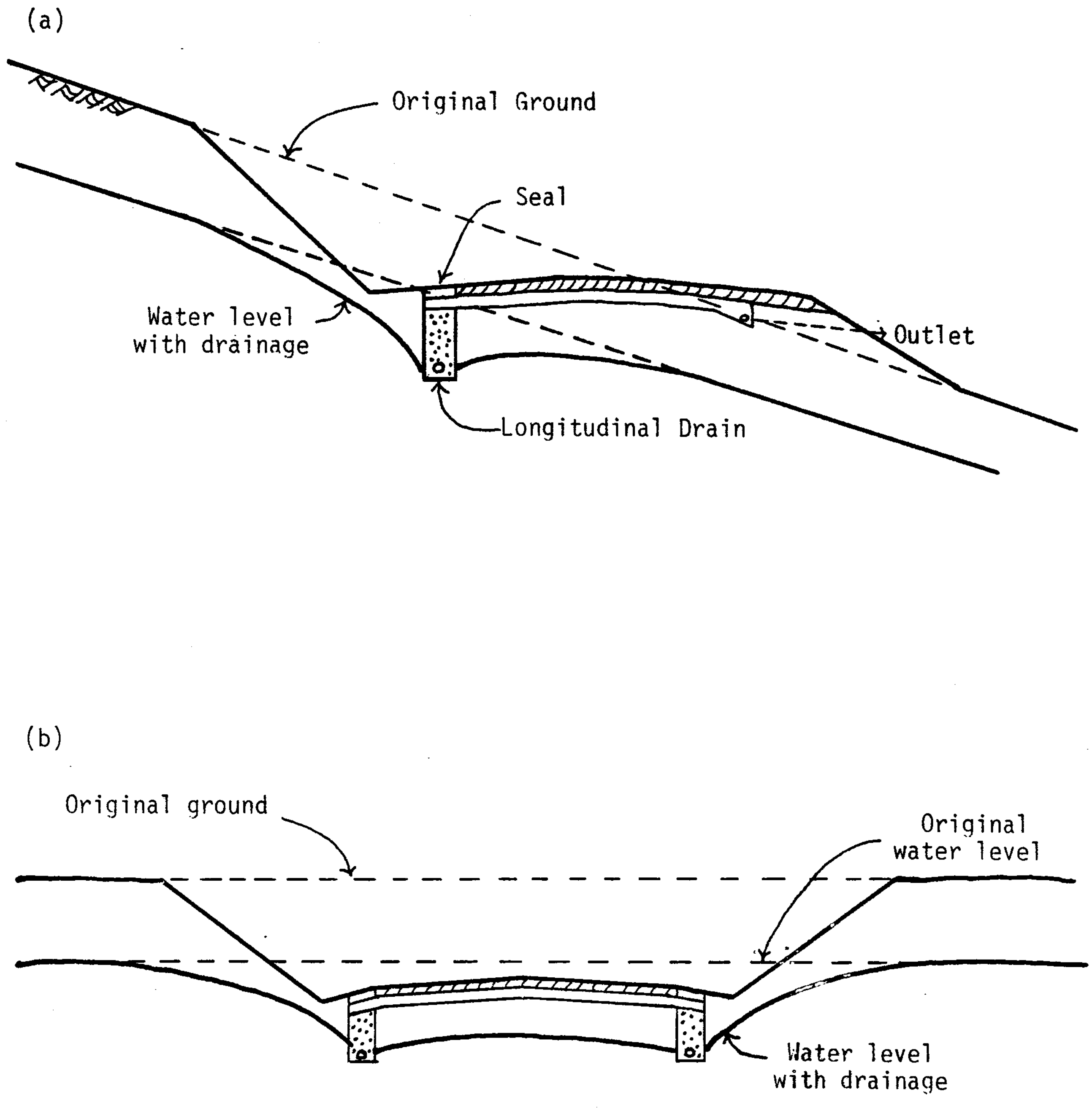


Figure 3.1 Longitudinal Highway Drains

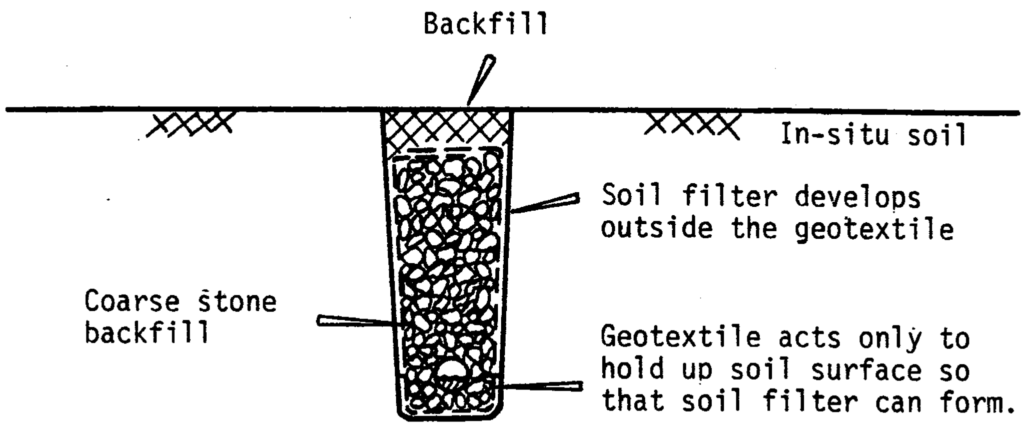


Figure 3.2 Geotextile drainage system

It has been claimed that geotextiles offer comparable performance to graded granular filters at a lower cost (12). The lower cost being attributed to the high transport and material costs associated with the traditional graded aggregate. Fabrics may also help in speeding up the construction process due to their ease of placement.

Difficulties in designing a fabric filter stem from problems in measuring fabric permeability and pore size. These properties are critical in fabric selection for preventing piping and clogging. Filter selection is discussed in the section entitled "Selecting a Geotextile for Drainage."

3.2 Filtering Mechanism

Soil filtration with geotextiles is a complex process as is soil filtration with granular filters. The mechanism by which a geotextile filter works is one of separation rather than filtration. A filter by definition is a material which removes suspended particles from a solution, and this suggests that a filter will eventually plug. Rather than directly filtering the soil, the geotextiles presence causes the soil to build up its own filter (Figure 3.3).

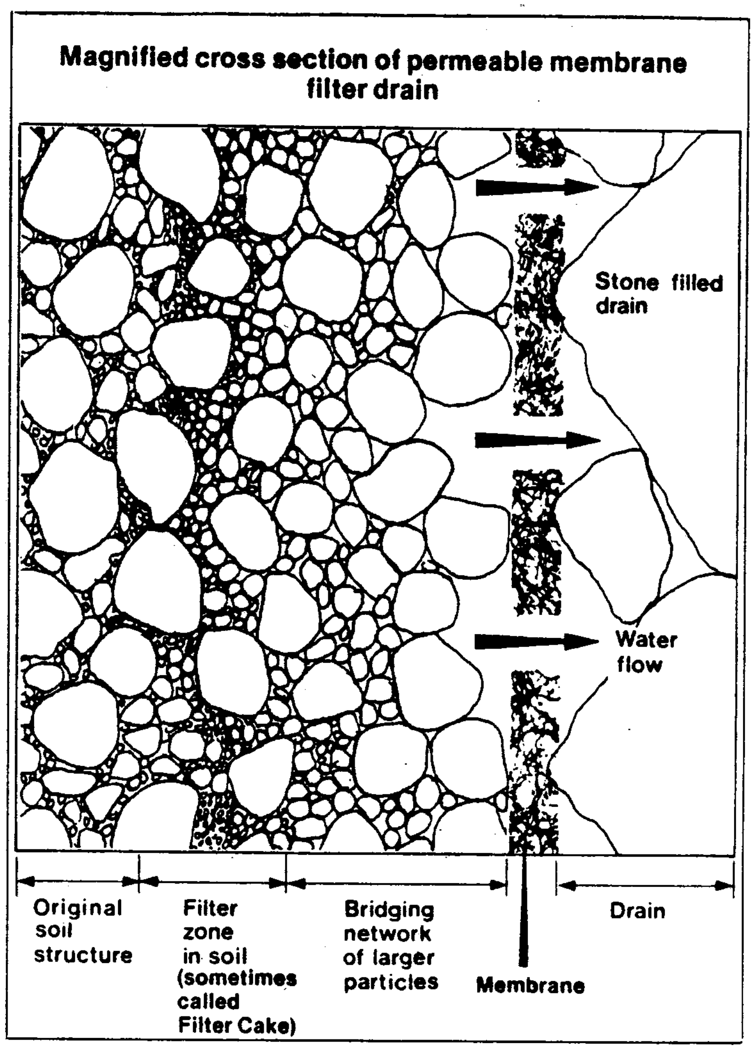


Figure 3.3 Detailed distribution of soil particles behind a permeable filter membrane subsequent to soil filter formation (10)

When a geotextile is used in a subsurface drain, a complex chain of events occur between the geotextile and the soil particles. As water begins to flow through the geotextile, it will carry fine soil particles from a layer immediately adjacent to the geotextile into and through the geotextile. Larger soil particles from this same layer will form a "bridging network" against the geotextile (Figure 3.3). Fine soil particles will fall in behind this bridge network to form a natural graded filter (soil filter), adjacent to the geotextile. Since very few fines will be able to pass the soil filter, the fabric will not clog. As seen in Figure 3.3, the fines adjacent to the geotextile have been washed out leaving a bridging network. Behind this layer another layer of lower permeability and a larger percentage of fines is found. This layer is often called a "filter cake," but this suggests an impermeable layer which is not necessarily true. This layer is now more commonly known as the "soil filter."

In a conventional drain there is not a geotextile to support a bridge network, thus the internal bridge network is not formed. It is important to note that the "soil filter" layer is a reverse graded granular filter with the smallest particles farthest from the drain.

3.3 Experimental Laboratory Findings

Pore characteristics of nonwovens have been found to be more variable than those for woven geotextiles. This is due to the manufacturing process and higher elongations under load. New composite geotextiles are being developed that will provide the filtering characteristics of a nonwoven fabric and the stiffness characteristics of woven fabric. For example, a high strength filter fabric can be made by bonding a nonwoven filter fabric to a high modulus woven fabric.

Long-term permeability tests by Koerner (13) indicate that the presence of a fabric in a soil results in a time-dependent loss in flow rate for the soil-fabric system. With woven and nonwoven needled fabrics, a constant flow rate was established at approximately 100 hours for all soils tested, except for silty clay soils (Figures 3.4 and 3.5). Flow rates for silty clay soils continue to drop with time. This indicates that silty clay soils may eventually block the geotextile. Thus it can be implied that the fabrics tested should not be used in drainage applications with these silty clays.

The U.S. Army Corps of Engineers (39,16) have developed the Gradient Ratio test as a direct measure of geotextile clogging potential. The Gradient Ratio apparatus is a constant head permeameter with 8 piezometers as illustrated in Figure 3.6. The Gradient Ratio is defined as the hydraulic gradient through the lower 25 mm (1 in) of soil plus geotextile divided by the hydraulic gradient through the adjacent 50 mm (2 in) of soil above (between 25 mm (1 in) and 75 mm (3 in) above the geotextile). A limiting value of 3.0 for the Gradient Ratio has been established by the Corps. Values above 3.0 were found to signify excessive geotextile clogging.

Koerner (13) and Rycroft (14) conclude that the flow through soil/fabric systems is governed initially by the hydraulic conductivity of the soil, and finally by the soil/fabric interaction. Koerner (13) and Marks (15) have concluded that long-term flow tests are needed to observe this phenomenon. Marks (15) maintains that the gradient ratio test should continue until the gradient ratio

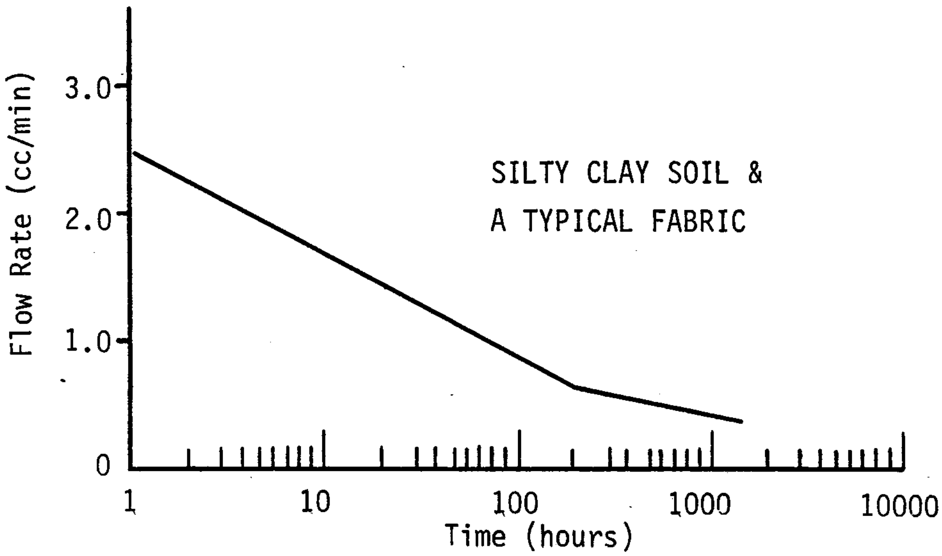


Figure 3.4 Typical Long-Term Flow Curve for Silty Clay Soil With Geotextile.

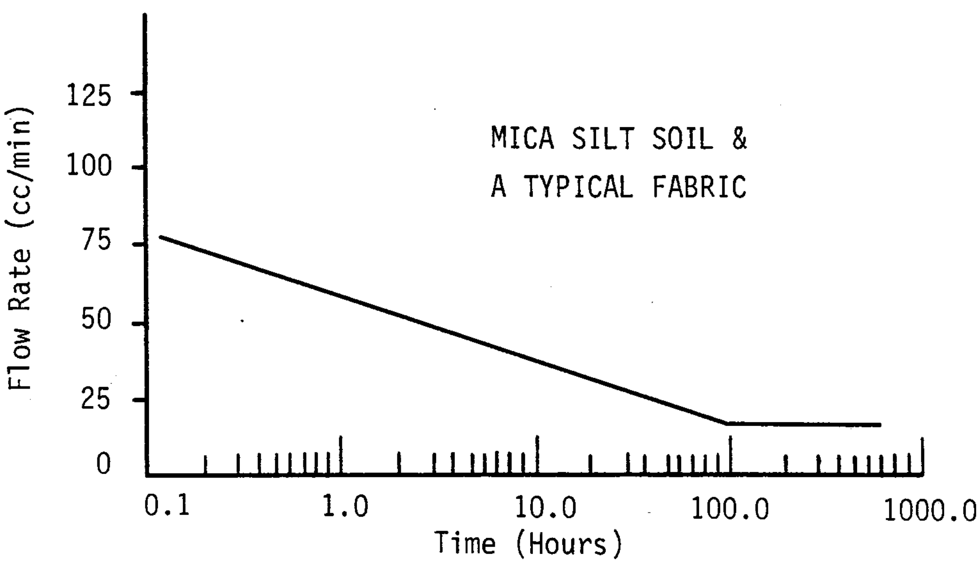


Figure 3.5 Typical Long-Term Flow Curve for Sands and Silts With a Geotextile.

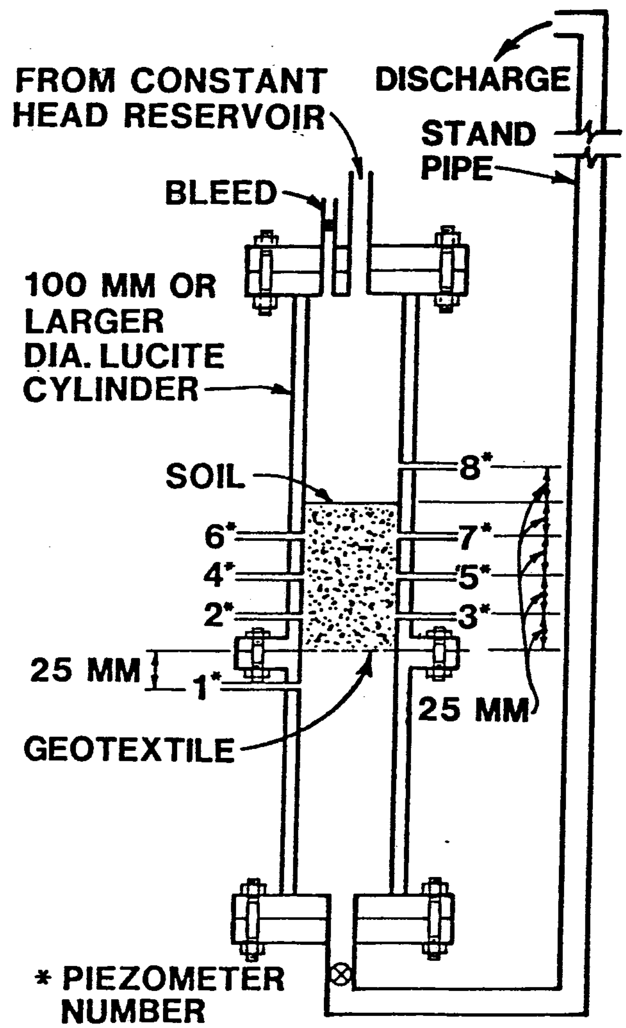


Figure 3.6. Cross-section Detail of U.S. Army Corps of Engineers Gradient Ratio Test Permeameter

is constant, thus making it a long term test in many cases. Tan (17) concludes that the present Corps criteria may apply to systems with coarse sand and large water velocities, but fine sands containing more than 30% silt and/or nonswelling clay will control and the present Corps standards should not apply.

Marks (15) contends that flow tests should be performed under intermittent flow conditions, similar to what would be expected in actual drainage conditions. Steward warns that the gradient ratio test has not been verified by field tests (5), but this also applies to other flow rate tests.

Thus, there is often conflicting views in the literature with regard to the selection/evaluation of geotextiles in a soil drainage system.

3.4 Field Applications

Although there have been numerous installations of geotextiles in underdrain systems, very few if any, have been monitored to determine long term performance. The most common measure of short term performance has been visual inspection of effluent from selected drains. Clear effluent indicates that the drains are filtering well, however it does not indicate what the long term clogging potential will be or what pore pressures will be developed in the system.

There is a lack of long term performance data in the literature. This is disturbing as several laboratory studies (13) have indicated long term clogging with certain soil types.

3.5 Selecting a Geotextile for Drainage

Design criteria for geotextiles in drainage applications are based on criteria established for granular filters by Terzaghi (18) which were later expanded upon by the United States Waterway Experiment Station and Cedergren (19). The following criteria have been established for filter materials in granular filters:

$$D_{15} \text{ Filter} < 5 \times D_{85} \text{ Soil} \tag{1}$$

$$D_{15} \text{ Filter} > 5 \times D_{15} \text{ Soil} \tag{2}$$

Equation 1 is the piping requirement for granular materials which states that migration of particles from a fine soil into a coarse filter soil can be prevented if D_{15} of the filter (D_{15} is the sieve size for which 15% of the soil particles will pass) is greater than 5 times D_{85} of the soil being protected (D_{85} corresponds to the sieve size for which 85% of the soil particles will pass). Equation 2 is the permeability requirement for granular filters which states that the effective diameter of the filter material must be five times the effective diameter of the soil being protected. See Figure 3.7 for acceptable gradations for granular and geotextile filters.

These design parameters have been indirectly applied to drains using geotextiles by specifying an indicative pore size for the geotextile.

$$O_I \leq D_{85} \text{ Soil}$$

$$O_I \geq D_{15} \text{ Soil}$$

O_I indicates the indicative pore size of the geotextile. The relationship between requirements for graded aggregate filters and geotextile filters can be seen in Figure 3.7. Note that the fabric criteria is based on pore size rather than particle size as in the

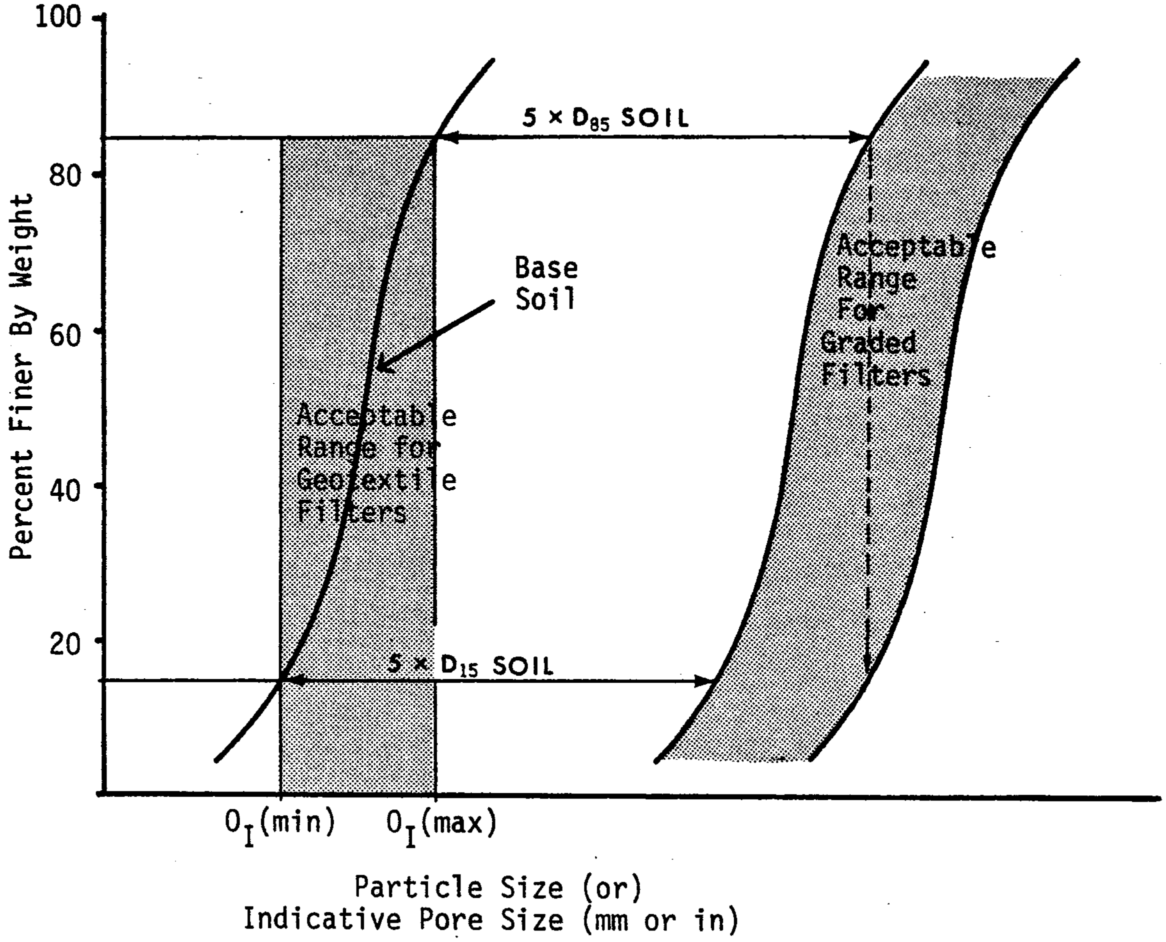


Figure 3.7. Requirements for Granular and Geotextile Drains

granular filter. The factor of five is found by considering tightly packed spherical particles of diameter d. It has been found that for a particle to pass between the large particles, it must be smaller than d/5.

There is no consensus as to what the limiting value should be for the indicative pore size. Calhoun suggests O_{95}, Delft Laboratories, Schober and Teindl suggest O_{90}, Cedergren suggests O_{85}, and Rankilor suggests O_{50}. O_{95} is a conservative value for the piping criterion, but this is not so for the permeability criterion. The permeability criterion is less important if the permeability of the geotextile is greater than that of the soil. The indicative pore size should be chosen as a function of the uniformity coefficient of the soil, soil type (clay, silt, sand, or combination), and the geotextile type (woven or nonwoven). The relationship between geotextile performance and these factors is unknown, and until more testing is done hypothetical values for indicative pore size will suffice. On the basis of an average of the values found, we are suggesting O_{90} for all soils other than those containing a significant amount of clays, which should be governed by O_{95}.

There are two methods available to determine the indicative pore size of geotextiles. The first method involves direct measurement of the pores by projecting a magnified image of the geotextile on to a screen and measuring the hole sizes. This method is not acceptable for nonwoven geotextiles and woven geotextiles with small and diverse pore sizes. The second method is an indirect measure of pore size using "reverse sieving," As used in the ASTM Apparent Opening Size

(AOS) Test. Reverse sieving is a process in which glass beads (Bollotini) of known diameter are shaken for 5 minutes on a sample of fabric lying in a coarse sieve. The weight of the particles of each size fraction passing through the geotextile is recorded and plotted on a graph similar to that for display of soil particle gradation (Figure 3.8). Figure 3.7 graphically shows filter requirements for granular and geotextile drains.

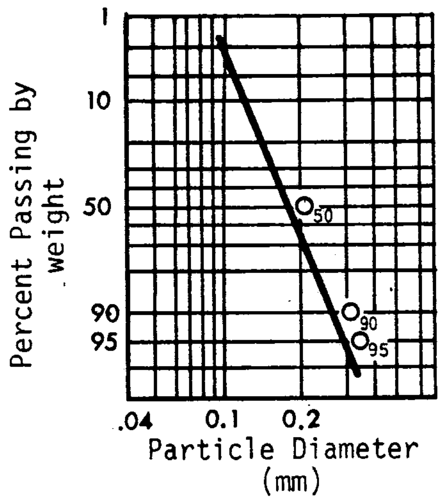


Figure 3.8 Geotextile pore size distribution

Other factors influencing fabric selection include dynamic loadings and intermittent flow. How these factors influence filter performance is uncertain at this time.

Another test in addition to the reverse sieve analysis is required to determine the performance of a particular soil-geotextile combination. The gradient ratio test can be used to measure the blinding or clogging potential of a geotextile in a given soil. If a geotextile clogs, it may no longer satisfy the permeability criterion, that is, the permeability of the fabric must be greater than that of the potential soil.

The gradient ratio, as described in Section 3.3, is the ratio of the seepage gradient through the fabric and 1 inch of soil to the gradient through an adjacent 2 inches of soil. If the gradient ratio reaches or exceeds a value of 3.0, the fabric-soil combination being tested should not be used.

3.6 Recommended Field and Lab Testing

Geotextiles are becoming popular in subsurface drainage systems. However, little is known about their long term performance. The best way to learn more about their performance is to instrument drains with piezometers, recording flow rates, and sampling effluent for soil contamination. Sections of the drain should be excavated and checked for clogging and sedimentation.

A laboratory testing program should be devised to check geotextiles to be used in drainage applications for their hydraulic properties in addition to the general requirements found in Table 8.2. The most significant tests to determine whether a geotextile is compatible with a given soil type for drainage applications are the gradient ratio test and reverse sieving.

Permeability tests on geotextiles alone do not represent common field conditions. In addition to this, it is very difficult to determine the permeability of a thin membrane (geotextile). A volume flow rate can be measured under constant or falling head to compare or index geotextiles. This too does not represent field conditions. Soil/geotextile permeability tests or hydraulic gradient tests are more representative of field conditions.

The reverse sieving technique, such as the ASTM AOS test, should be used on both woven and nonwoven geotextiles to determine indicative pore size. Questions have been raised regarding the applicability of this test to nonwoven geotextiles. However, this is the best method available at this time to determine indicative pore size for a nonwoven geotextile. It should also be noted that these tests do not indicate the actual properties of a nonwoven geotextile in the field, where the geotextile is subject to strains, intermittent flow, and confining pressure. Tentative limits and proposed testing procedures for geotextiles to be used in drainage applications are summarized in Table 8.2, in Section 8 of this report.

4. SEPARATION

4.1 Introduction

Separation is the physical process of preventing two dissimilar materials from mixing. The most common use, in highways, is to prevent or minimize movement of aggregate base materials into weak subgrade soils.

Often highway designers find it necessary to stabilize a soft subgrade (lime, cement, etc.) or to place a blanket of sand or similar material over a soft subgrade to minimize subgrade intrusion into the granular base. Texas frequently applies lime to poor clays subgrades, 6% lime with a 6-8 inch layer. Based on construction cost data presented in (33), typical lime stabilization currently costs approximately $3.00 per square yard. With the price of a typical geotextile being less than $1.00 per square yard, there is clearly some potential for cost-savings.

4.2 Separation Mechanism

If a geotextile is used as a separator, its primary function, as shown in Figure 4.1, is to prevent intrusion and mixing and to ensure that the design boundaries remain well defined and do not become blurred during use. This continued definition of design boundaries or design geometry will assist in ensuring that the working mechanics of the pavement structure, as specified by the design engineer, will function throughout the design life (7).

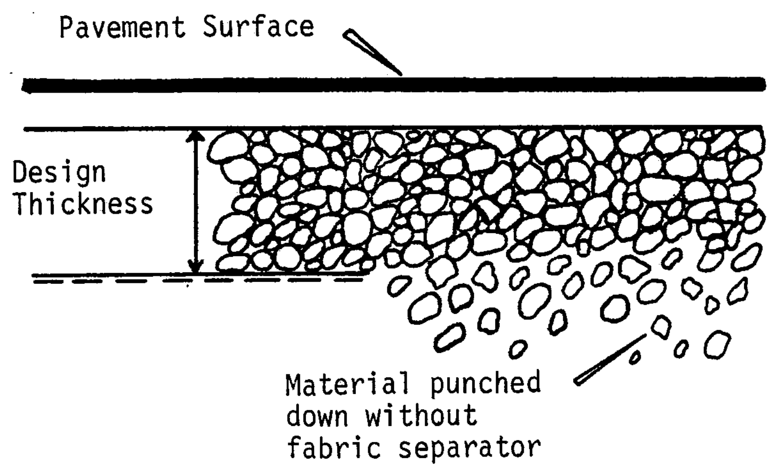


Figure 4.1 Using a Geotextile as a Separator to maintain design boundaries (7)

The separation function of geotextiles is purely physical. The two materials, aggregate base course and subgrade have a physical boundary - the geotextile. By the continued existence of this design boundary, the aggregate base course maintains its strength and through compaction improved load distribution abilities. The well known adverse effects of increased fines content on pertinent engineering properties (shear strength, resilient modulus, permanent deformation, moisture sensitivity, permeability, frost action behavior) of the aggregate base are avoided (22).

4.3 Laboratory Testing

Sowers and Collins (20) investigating the mechanisms of geotextile-aggregate support in low-cost roads state that, "more important, the geotextile prevents the intrusion of the soft subgrade into the cracks and voids of the aggregate. Thus, the load spreading ability of the aggregate is maintained."

Barenberg, Dowland, and Hales (21) working with Mirafi geotextile conclude from their tests that geotextiles are effective as separators.

Thompson and Raad (22) state that, "Many beneficial effects can be achieved through the separation function."

4.4 Field Testing and Applications

Steward and Mohney (23) report on the use of geotextiles as a separator between aggregate base and subgrade for low-volume forest roads.

Ruddock, Petter, and McAvoy (24) performed full-scale experiments on granular and bituminous road pavements laid on geotextiles on a subgrade of clay (LL=50%, PL=23%, $w_{in\ situ}$=26%) using three woven, one nonwoven, and one melt-bonded geotextile, they found, "the separation of the sub-base (crushed granite) from the subgrade was effectively maintained by all the geotextiles, only a slight coloration of the subgrade showing in the bottom of the sub-base over permeable geotextiles." In contrast they report, "In the control section the sub-base and subgrade were intermixed to a depth of about 50 mm over the whole section." They conclude that all geotextiles used were effective as separating layers between the clay subgrade and well graded sub-base material.

Raumann (25) in the development of design considerations for using geotextiles in unpaved roads relies heavily on the separation function.

In field applications Steward, Williamson, and Mohney (5) of the U.S. Forest Service discuss, in some detail, the separation function and present a technique which allows a calculation of the reduction in aggregate base thickness when using a geotextile as a separator.

Bell and Hicks (4) discuss the separation function as applicable to highways and include information on selecting geotextiles.

Perhaps the single greatest use of geotextiles for separation is in the railroad industry. Newby (2) reports a wide use of geotextiles to separate ballast and subgrade and presents, in some detail, the principle reasons for the specifications on geotextiles that are presently used by Southern Pacific Railroad. It is interesting to note that these specifications call for nonwoven geotextiles, "because woven geotextiles do not have planar permeability and it is anticipated that voids would open under tensile stress resulting in penetration of fine soils."

4.5 Limitations and Significant Parameters

Originally geotextiles were used as separators between aggregate base and soft or otherwise undesirable subgrade. Field observations were that the geotextile contributed more than simply separation. Within a few years there was, among users of geotextiles, a reference to "subgrade stabilization." Herein it was implied that using a geotextile between the aggregate base and subgrade resulted in the geotextile performing at least one or more of four functions:

1. Separation
2. Drainage
3. Filtration
4. Reinforcement.

In terms of the time parameter - separation is a full time function and is performed throughout the life of the system; drainage involves providing a channel through which excess water may move out of the subgrade and away from the pavement structure - the potential for drainage must be full time, however the actual function occurs during wet conditions; filtration is simply preventing the migration of fines from the subgrade into the base and degrading the quality of the base - again - the potential must be full time but the function is sporadic depending on the moisture and loading conditions; reinforcement or strengthening is the process by which the fabric, via membrane action, assists in load carrying. However the reinforcing contribution of fabrics is uncertain. This will be discussed in some detail in Section 5.

Filtration or migration of fines has been observed in the laboratory and field (24,26). As previously discussed in this section, both laboratory and field work have shown that geotextiles can and do prevent the movement of aggregate base down into the subgrade soil. However, it has also been shown that dynamic loads and soft clay subgrades have resulted in clay migration through the geotextile and contaminating the aggregate base. Most agree that

20-30% fines (smaller than a No. 200 sieve) can result in a substantial reduction in the strength of an aggregate. In the case of active clays this percentage may be reduced to values in the range of 10-20%. Several conditions must be met for migration to occur - obviously migration will occur at the boundary and will likely require high pore water pressures. It seems that a granular filter or separator provides a volume in which the pore water pressures may be elevated and then dissipate in all directions. Because of the thinness of the geotextile inplane migration of pore water may not be possible. Hence, depending on the magnitude of the load, the dwell time of the load and the period between load applications, pore pressures may become elevated in the system. If the period between load applications is low, then the pore pressures may become excessive and a water-soil slurry may form at the fabric soil interface. Under elevated pressures this slurry may migrate through the membrane. There is little published information on this phenomena, however, slurry formation at the fabric interface was noted in a railroad experimental fabric section (27). The fabric has been selected to allow the passage of water so as to satisfy the drainage requirement. In cases of elevated pore pressures it does not appear possible, at present, to manufacture a fabric that will prevent migration with some fine grained and dispersive soils.

Hoare (26) reports that the amount of soil migration increases linearly with the log of the number of applied load cycles, soil migrates through the fabric at the points of aggregate contact, the moisture content of the soil at the points of contact with a sub-base particle increases to a value close to its liquid limit......and the phenomenon of clay pumping is thought to be caused by this wet soil on the surface of the subgrade squeezing through the fabric. Bell and Snaith (28) from laboratory tests states that, "Although there are clearly several controlling variables, the influence of the O_{95} or effective opening size seems to be a major factor in controlling clay fines migration." They report that this is particularly strong in the case of woven fabrics but is also apparent when comparing other filter types. Another important factor was a clear dependence of contamination value on initial subgrade moisture content for nonwoven filters. This same effect was also noted by McCullough (29) for woven geotextiles although it was less clearly defined. Bell and Snaith (28) further state that, "The problem of prevention of clay fines migrating from a cohesive subgrade into a granular sub-base differs from many other filtration problems in several respects. Firstly, the subgrade, sub-base and the intervening filter layers are subjected to dynamically varying normal and shear stresses. Secondly, the flow through the filter may be of the reversing type. Thirdly, the filter is essentially required to prevent the passage of what is believed to be a clay slurry and yet allow the free passage of water. For these reasons it is unlikely that any economic filter method will completely prevent fines contamination......thus the object of selecting a filter......must be to limit fines migration to an acceptable level."

4.6 Recommendations for Laboratory Testing

Geotextiles have applications in highway construction. As a separator, their widest use has been in low-cost, low-volume roads built on difficult subgrades. However, due to this application most of the literature deals with an investigation of what a geotextile actually does in such a pavement structure and then translating this knowledge into a design procedure. The literature cites few examples of the use of a geotextile as a separator between base and subgrade in asphalt surfaced pavements. Should a geotextile be used in this latter type structure, perhaps its important functions will be separation and filtration. The filtration function will be under dynamic loads and probably intermittent as the moisture content of the top few inches of subgrade changes with time and environmental conditions.

For geotextile used as a separator between base and subgrade in a surfaced pavement structure there are several desirable properties related to the separation function and filtration under dynamic loads. These deal primarily with mechanical properties, dimensional stability properties, water transmission and soil filtration properties.

Aside from the properties required to resist the environment (UV light, bacteria, algae, pH, etc.) emphasis must be placed on providing properties to resist conditions of transportation, storage and contruction.

For separation - the actual in use properties which seem most significant are:

Strength - Tensile strength as measured by some sort of test similar to grab test. It is likely that the range of allowable values and the optimum value will be influenced more by construction needs than by in use, separation, needs. It is recommended that the laboratory be equipped so that the ASTM Grab Tensile Test and Wide Width Tensile Test may be performed.

Tear Strength - To serve as a separator the geotextile must not lose its continuity. If some discontinuity in the geotextile occurs, for whatever reason, the geotextile must possess sufficient resistance to minimize the propagation of this discontinuity. Perhaps the most likely test is the trapezoid tear test. It is recommended that the laboratory be equipped to perform this test.

Puncture Strength - Punctures are failures in the geotextile and are to be avoided. However, to ensure that such will not occur during construction (considered to be the most dangerous time) or use, some minimum resistance must be offered by the geotextile to puncture. It does not appear that ASTM is considering such a test. Thus, some consideration should be given to investigating the Cone drop test or some alternate to this. It is recommended that the laboratory be outfitted to perform this test.

Burst Strength - The variable nature of the subgrade strength will result in soft spots wherein at some locations subgrade strain will exceed that at other locations. In the zone of larger subgrade strain, the separating geotextile will be required to deform and resist the forces generated by the aggregate being pushed into it while under load. Thus, the emphasis on the so-called "burst strength." It does not appear that ASTM is considering such a test. It is recommended that the Mullen burst test should be available in the laboratory.

Modulus - No special test is recommended to evaluate the geotextile modulus since such information should be available from the tensile strength test.

Elongation - Information on elongation could be collected from the tensile strength test. In use, the separator geotextile will be subject to strain. One example has been given in the burst test discussion. Another is during the compaction and traffic loads on the aggregate base, Figure 4.2 (24) which illustrates likely movements of the aggregate relative to the geotextile as the aggregate and base deform under load. This Figure can also be used to explain the possible propagation of a tear. For instance, lengths L1 and L2 may be strained much more than the average measured over a typical gauge length because the particles bite into the geotextile and move it with them. If the local elongation or strain in the geotextile rises to the rupture strain, a tear is initiated; the existence of the tear reduces horizontal restraint on the sub-base and under repeated loading allows greater deformation and progressive extension of the tear (24).

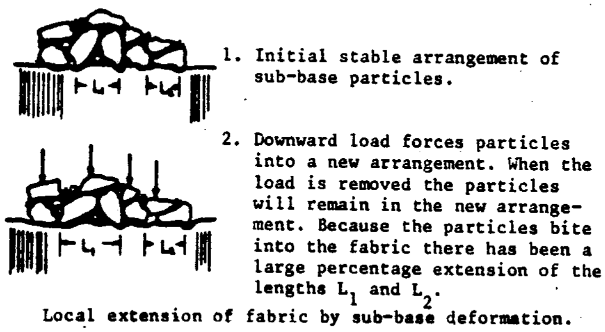


Figure 4.2 Possible Movement of Aggregates to Contact With a Geotextile

For the filtration function, information as provided by the following tests is needed:

Rate of Water Flow - At the present time the rate of water flow under a constant head is recommended rather than a permeability test. In keeping with some of the reports in the literature a constant head of 4 inches of water is recommended.

Equivalent Open Size - Soil migration through the Separator geotextile is considered by many to be a significant problem, particularly for dispersive soils. To provide information on the ability of the geotextile to filter soil particles, it is recommended that the Apparent Open Size (glass beads) test be available. This test should be followed by a long-term laboratory test using the geotextile and a representative sample of the inplace soil. Combining the results of such tests may provide a more realistic means of evaluating a geotextile to serve as a filter under dynamic loads.

Gradient Ratio Test - To provide information on the clogging potential of the geotextile, the gradient ratio test is recommended. It appears that this is soon to be an ASTM approved test. The laboratory should be capable of performing this test.

Thickness - In the case of nonwovens, the thickness may become important as a means of providing in plane water transmission and rapid reduction of pore water pressure.

Drapeability or Flexibility - It seems that any of the existing geotextiles which meet the elongation requirement, the burst strength requirement, etc., will be flexible enough for separator use. However, some acceptable method to measure or indicate drapeability/flexibility should be developed.

Properties of Secondary interest include:

Friction-Adhesion - It is conceded that the geotextile separator may be subject to friction from movement of the aggregate in contact and that adhesion of the subgrades and geotextile may limit strains of the subgrade near the contact junction. However, these are not considered primary at this time.

In summary, if it is concluded that there are applications for geotextiles as separators in surfaced pavement structures in Texas, the laboratory should be equipped to perform the tests as recommended. Further, it is recommended that a nonwoven geotextile be considered and that a series of laboratory and controlled field tests be performed to evaluate the properties stated herein as important. Tentative limits for these proposed tests are shown in Table 8.3.

5. REINFORCEMENT

5.1 Introduction

Reinforcement is said to be present in a soil-geotextile system when the geotextile, acting as a tension member, contributes to the load bearing capacity of the system. Reinforcing benefits due to geotextiles are commonly associated with high deformation systems such as unpaved forestry or haul roads in which large ruts (2-4 inches) are acceptable. The improved performance of unpaved roads due to the combined functions of geotextiles has led to design procedures which allow for reductions in aggregate thickness (5,8,30). Most design procedures available are empirically based and have little experimental data or theoretical basis to back them up.

After surveying the available literature, it is doubtful that any significant reinforcing can be achieved in low deformation systems, where only minor rutting is permissible. This is primarily because

a) the currently available geofabrics have too low a modulus value

b) there is no way to tension the fabric within the pavement system

c) the creep properties of the geofabric are unknown.

Nevertheless, several manufacturers are producing high tensile strength grids and equipment to tension geofabrics during laydown. In the near future, new geofabric may be available to significantly reinforce pavements.

In this section, the current theories on reinforcing mechanisms will be presented and the available laboratory and field results will be discussed.

5.2 Reinforcing Mechanisms

Geotextiles appear to have two primary reinforcing functions in soil-geotextile-aggregate (SGA) systems, "membrane-type" support and increased lateral restraint of cohesionless base materials under applied vehicle loads. Separation of the base and subgrade soil is considered to be a separate function of the geotextile.

Cohesionless base materials derive their strength from frictional contact between the granular particles. The frictional force is maximized when the particles are clean, dry, and in firm contact with one another. Wheel loads applied to the SGA system result in the development of tensile strains at the bottom of the aggregate layer. Since the cohesionless base materials have basically no tensile strength, the tensile strains cause the base material to spread in the horizontal direction. When a geotextile is placed at the aggregate-subgrade interface, tensile stresses are developed in the geotextile through aggregate-geotextile friction when the base material attempts to spread horizontally (Figure 5.1). The geotextile resists stretching and inward-directed shear stresses are developed on the base material and subgrade.

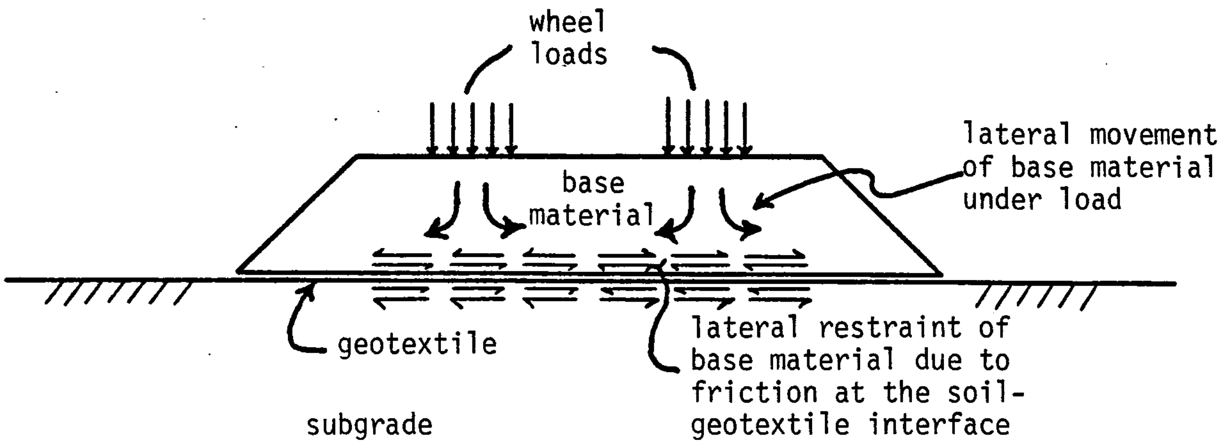


FIGURE 5.1 Lateral Restraint of Cohesionless Base Material

Lateral confinement of the base material increases its resilient modulus thus reducing deformations under vehicular loadings. Increasing the difference between the modulus of the base material and that of the subgrade (modular ratio) increases the potential for significant Burmister-type stress reductions in the subgrade (36). Thus reducing the magnitude of stresses transmitted to the lower modulus subgrade. Even a relatively small change in the horizontal stress distribution can have a significant effect on system performance (37).

The ability of the geotextile to provide lateral restraint will depend on the coefficient of friction which can be developed between the geotextile and cover material, the ability of the geotextile to develop significant horizontal shear stresses at low strains (i.e. high modulus), and the geotextiles resistance to puncture and abrasion from cover materials (Haliburton and Fowler 1980).

Membrane-type support becomes available when a wheel load induces a localized deformation of the base material and subgrade, the geotextile is also strained and develops in-plane tensile stressses when sufficient friction and adhesion are available to prevent geotextile slippage. A stress component perpendicular to the plane of the fabric is developed with a magnitude equal to the difference in the normal stress above and below the geotextile (Figure 5.2). Kinney (34) calls this stress the fabric induced normal stress.

The fabric induced normal stress can also be found by dividing the fabric tensile stress by the radius of curvature of the fabric at that point (34). The fabric induced normal stress reduces the magnitude of the normal stress on the subgrade, under the wheel load and increases the normal stress on the subgrade throughout the concave downward portion of the pavement cross-section (Figure 5.2).

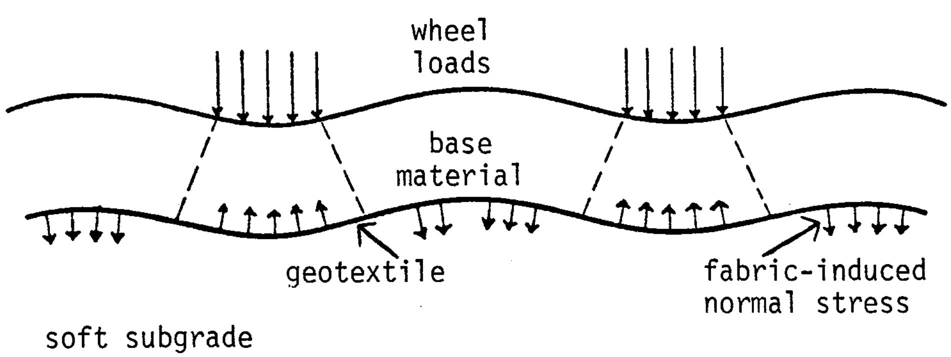


FIGURE 5.2 Fabric Induced Normal Stresses

Low Deformation Systems

Lateral restraint and membrane-type action work well to explain the behavior of high deformation SGA systems; however, the applicability of these mechanisms to low deformation systems is somewhat questionable. Kinney (34) reported that significant deformation appears to be necessary for the geotextile to act as a reinforcing member. Steward, Williamson, and Mohney (5) report that improvement in soil bearing capacity from subgrade restraint will only occur for very weak subgrades with a California Bearing Ratio (CBR) of 3 or less (Texas Triaxial Class > 5.0).

Geotextiles in use today do not have moduli high enough to improve the deformation characteristics of asphalt or concrete paved roads (4). If, however, the geotextile restrains the aggregate base material in the horizontal direction even slightly, it could significantly improve the SGA system performance (34). Ruddock, Potter, and McAvoy (24) found evidence suggesting that the transient transverse strain in the soil was reduced slightly in a paved low deformation system; however, they concluded that the geotextile presence did not improve the structural behavior of bituminous pavement systems.

Based on the limited data available, it is difficult to substantiate the reinforcing benefits of geotextiles in paved roads. If geotextiles are to improve low deformation SGA system performance, the improvement will most likely be due to improved lateral restraint of the aggregate base material. Confinement of the base material is limited to the stress-strain characteristics of the geotextile. If the geotextile can develop high stresses at low strains while resisting slippage at the interface, then an improvement in aggregate confinement can be expected; however, the ability of the system to maintain this improvement is dependent on the creep characteristics of the geotextile.

5.3 Laboratory Results

Kinney (1979)

Kinney (34) developed a two-dimensional laboratory model of an unpaved road in order to evaluate the strengthening effects of a geotextile on a soil-geotextile-aggregate (SGA) system when rutting occurs. A mathematical model called the Fabric Tension Model was developed to calculate the stresses and the strain energy stored in the fabric.

Kinney found that geotextiles improved the stability of high deformation SGA systems through structural reinforcement. The geotextile improves the stress and strain distribution within the SGA system when rutting occurs. As the rut develops, a decrease in the normal stress on the subgrade under the load is observed while normal stress on the heaved portion (Figure 5.2). Inward shear stresses due to the geotextile are developed on both sides of the geotextile.

Kinney (1982)

Kinney (35) reported on a series of small scale laboratory tests which give some insight into the effect of a geotextile on a soil-geotextile-aggregate (SGA) system. Kinney found that the geotextiles used (woven and non-woven) adhered to the clay subbase material better than the porous aggregate without a geotextile. This adhesion reduces the lateral spreading of the clay and, thus, displacements in high deformation systems. Kinney also found the effect of the geotextile to diminish with greater aggregate thickness, and the necessity of high deformations for the geotextile to act as a reinforcing member.

Robnett, Lai, and Murch (1982)

In a laboratory test with an SGA system, Robnett, Lai, and Murch (36) found the modulus of the geotextile to be the single most important fabric property governing system behavior. High modulus fabrics were found to result in less rutting and better system performance.

Haliburton and Barron (1982)

Haliburton and Barron (32) presented an optimum-depth design method for unsurfaced geotextile-reinforced roads. In laboratory tests, an SGA system was modeled and loaded until large deformations occurred. Geotextiles were found to improve SGA system behavior; however, no marked difference was noted among the three fabrics tested, indicating that the membrane-type support component contributed little to the load-carrying capabilities of the system.

The depth of the fabric was found to be more important than fabric type in this study. When the fabric is placed on a weak material and overlaid by an optimum depth of aggregate base material, the Burmister-type modulus ratio effects can be maximized. The Burmister effects result in a stress reduction such that the actual subgrade stress immediately below the fabric is reduced by as must as 50 percent of that predicted Boussinesq theory. Haliburton found the optimum depth to be approximately one-third the width of the loaded area.

Barksdale, Robnett, and Lai (1982)

A finite element program was used to model the effects of geotextiles in high deformation systems (38,40). Model tests were conducted using both 0.9 and 2.5m diameter circular test tanks to simulate aggregate surfaced haul roads. Both the model tests and the GAPPS7 program indicate that geotextiles improve the stress and strain distribution in high deformation systems.

5.4 Field Tests

Ruddock, Potter, and McAvoy (1982)

In this study, full scale paved and unpaved SGA pavement systems were constructed over a soft clay subgrade by the Transport and Road Research Laboratory. In the unsurfaced pavements, geotextiles were found to reduce permanent surface deformation and permanent subgrade strains; however, transient vertical stress and strain in the soil were not changed. In sections overlayed with a "hot mix," the structural performance of the system was not improved with the presence of the geotextile.

Webster and Walkins (1977)

Webster and Walkins (37) presented results of full-scale SGA tests performed by the Waterways Experiment Station. An unsurfaced road was constructed over a very soft subgrade and loaded by a slow moving truck. Geotextiles were found to greatly improve the permanent deformation characteristics of the system. The sections with geotextiles appeared to become more stable as rut depths increased, even under increased loads.

Sowers, Collins, and Miller (1982)

Sowers, Collins, and Miller (20) described laboratory and field tests used to investigate the mechanism of geotextile-aggregate support in unpaved roads. After initial tests with a plate loading test apparatus, resulting deflections and failure loads failed to correlate with comparative loads and deflections observed in the field. At this point, the researchers involved decided to rely on field tests. From these tests a procedure was developed for determining geotextile strains for a specified axle load.

Steward and Mohney (1978)

Steward, Williamson, and Mohney (5) found that the presence of a geotextile and cover material prevented local shear failure (rutting) of soft subgrade soils; these subgrades failed in general shear when overloaded. Reinforcing benefits were found to be available for subgrade with a California Bearing ratio (CBR) of 3 or less.

Although large deformations were measured, no strains were measured on the geotextile in the test section. This indicated to the researchers that the geotextile strain characteristics were not necessary for design consideration.

5.5 Selecting a Geotextile for Reinforcement

Due to the lack of proven theories relating geotextile performance in SGA systems to soil properties and traffic loadings, it is difficult to select a geotextile based on its physical and mechanical properties. Properties of primary importance for reinforcement include fabric modulus, tensile strength, and creep characteristics of the fabric.

In high deformation systems, fabrics with high moduli reduce subgrade stress upon rut formation. The reduction in subgrade stress is due to tension in the fabric which is proportional to the fabrics modulus. The greater the fabric modulus, the greater the potential stress reduction in high deformation systems. The long term tensile strength of the geotextile is limited by its creep characteristics. The ability to apply a fabric's creep properties to design are limited; however, comparison of geotextile creep properties would be useful in the geotextile selection process. Geotextiles with the least tendency to creep are the most desirable since they maintain tensile stresses more effectively.

Friction developed at the geotextile interfaces is also of vital importance since tension developed in the geotextile is transferred to the base material and subgrade through friction at the interface.

Ideally, the minimum acceptable soil-geotextile friction should be at least equal to the soil friction in order to prevent slippage at the soil-geotextile interface. The greatest friction between geotextile and soil occurs when there is a maximum conformity of the geotextile to the soil surface and a high degree of soil-geotextile interlocking (4). Pull out tests with various geotextiles in a direct shear test box can be used to determine which geotextiles have the best friction characteristics for a given soil.

5.6 Recommendations

Although benefits due to reinforcing appear to be minimal in low deformation pavement systems, there may be situations where geotextiles may act as filters and separators to improve system performance. Geotextiles have been known to improve performance of low deformation pavement systems; however, the mechanisms to which this improvement is due are uncertain. For this reason, it may be beneficial to select a fabric with a high modulus, high friction characteristics, and low creep properties if the geotextile is to be used in a low deformation pavement system.

Minimum requirements for selecting geotextiles for reinforcement are the same as those for separation, see Table 8.3. When given the task of selecting a geotextile for reinforcing from a range of geotextiles that meet the minimum specifications (Table 8.3), the designer should consider

a) the geotextile modulus (as measured in Wide Width Tensile tests)

b) creep potential (no standard test)

c) aggregate-geofabric-soil friction (no standard test, except (38).

The optimum geotextile has highest modulus, lowest creep potential and highest friction. However, standardized test procedures are not available to determine these parameters.

6. SILT FENCING

6.1 Introduction

Interest in silt fencing has increased in recent years as a means of controlling sedimentation in environmentally sensitive areas. The silt fence is a vertical barrier that intercepts surface runoff and sediment particles. It typically is composed of a geotextile supported on fencing or simply supported by posts. The bottom of the fabric is buried in the ground so that runoff will not flow beneath the barrier. The post and wire are structural elements of the system while the geotextile provides retention.

Several agencies, including the Corps of Engineers and the California DOT, have used silt fences constructed with geotextiles. Both woven and nonwovens have worked satisfactorily.

6.2 Mechanism

The mechanism describing how silt fences work is described in detail in (4). A summary of this is presented below.

"As the first water reaches the silt fence, the geotextile filters the solids from the water letting the water through. This is a true filtering action and the solid particles accumulate on the upstream face of the geotextile. As the soil cake builds up in thickness, it becomes relatively impermeable and water can no longer easily flow through it. This creates a small pond behind the silt fence causing the coarser particles to settle in the pond and only the finer particles reach the silt fence. If particles continue to reach the silt fence, the soil cake continues to build up causing the height of water and the size of the pond behind the silt fence to increase." Referring to Figure 6.1 below;

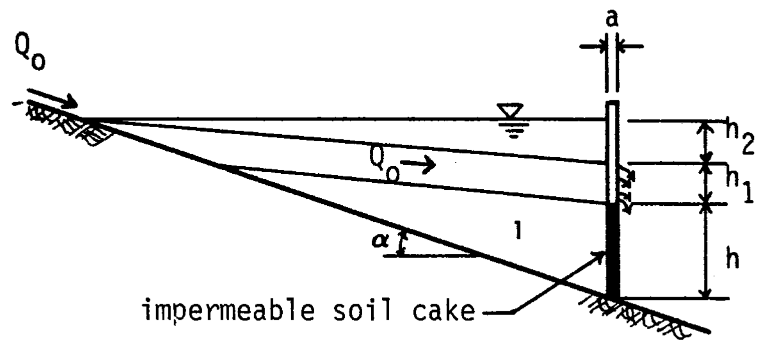


Figure 6.1 Runoff Behind and Through a Silt Fence

The increases in soil cake height (h) increase the length of the setting basin (l), therefore more and more particles drop into the settlement basin. The particles which reach the geotextile become finer and finer. With proper design, this process continues until the suspended particles which reach the fence become small enough that they are no longer filtered and pass through the fence, resulting in an equilibrium situation.

6.3 <u>Desirable Measurable Geotextile Properties</u>

For geotextiles to perform in silt fencing applications it must have the following properties.

1. Pore size small enough to retain most of the suspended sediment; however large enough to allow the finest particles

to pass.

2. Low enough threshold gradient to allow required flow volume without excess height of fence.

3. Adequate strength to resist the pressures of both water and sediment.

4. Reasonable tear resistance to facilitate mounting on posts and fence.

5. Adequate resistance to UV deterioration for the desired life of the fence.

6.4 Design for Silt Fence Applications

A rationale design procedure for silt fencing has been proposed (4,8). It requires knowledge of the geotextile tensile strength, permeability, threshold gradient, and pore size distribution as well as knowledge of anticipated site condition (inflows, size distribution of suspended solids, the quantity and size of particles which may pass through the fence, etc.)

6.5 Recommended Lab Testing Program

When considering geotextiles for silt fencing applications, the following should be specified.

a) Minimum Tensile Strength - To permit reasonable construction practices and ensure long term performance, a geotextile must have adequate strength to resist the pressures expected while in service. The Wide Width Tensile Test is recommended for this application. The minimum values of strength depend upon the construction technique to be used (is the geotextile supported by a wire fence or not?). It is also recommended that the geotextile have minimum trapezoidal tear resistance of 100 lbs. to allow reasonable construction practices.

b) Pore Sizes - Retaining solids and permitting water to pass is controlled by the fabric pore size and permeability. The geotextile pore size should be related to the suspended grain sizes by the following relationships (4):

$$AOS \geq 6\ D_p$$

$$AOS \leq D_{50}$$

where

D_p = maximum size of particle that is permitted to pass through.

D_{50} = 50% size of particles in runoff.

AOS = Geotextile Apparent Opening Size.

However, when the above is not practical, it has been found (4) that under most practical situations the following geotextile properties will ensure adequate performance:

- initial permeability > 10^{-2} cm/sec. (0.4×10^{-2} in/sec.)
- AOS between 70 and 100.

c) Durability - The geotextile also must have adequate UV resistance to survive for its expected life. The Xeon weathereometer is recommended for this purpose. For short term installations, 500 hours exposure is recommended, for long term installations (up to 3 years) 3000 hours in the weathereometer is recommended. In both cases, the fabric must retain 85% of its Wide Width tensile strength.

7. IMPERMEABLE BARRIERS (GEOMEMBRANES)

7.1 Introduction

The vast majority of the work reported with geofabrics has been performed with permeable fabrics (geotextiles). As discussed in other sections of this report, these permeable geofabrics are used for separation, reinforcing, drainage, and filtration. However, an area of growing interest is that of using impermeable geofabrics to extend the life of a pavement section. These impermeable geofabrics (known as Geomembranes by ASTM) are used either to prevent excessive moisture from reaching water susceptible soils or to intercept ground water flow which would have otherwise entered the pavement structure. Both of these applications will be described later in this section.

One problem encountered in preparing this analysis is that there is very little published information on performance of geomembranes in pavement systems and there is also a scarcity of laboratory test data. The Texas Highway Department, with its experimental projects in the San Antonio District, is one of the few agencies to report performance data on geomembranes in pavements.

7.2 Mechanism

In the applications to be described, the geomembranes simply act as a moisture barrier. Therefore, the basic requirement of the geomembrane is that

a) it is strong and flexible enough to withstand the installation process without puncturing or tearing, and

b) that it remains practically impermeable under working conditions.

7.3 Laboratory Results

Very few agencies, other than fabric manufacturers, have reported laboratory results on geomembranes relating to highway applications. One major concern is how the impermeability of these materials varies with time. The Texas Transportation Institute has developed a flow rate test, shown in Figure 7.1, to investigate the permittivity characteristics of these geomembranes. Long term tests (up to 6 months) have been carried out and very low permittivities (permeability/fabric thickness) have been determined. With any long term test such as these several special precautions need to be taken, such as:

a) to prevent water loss due to evaporation, the measuring cylinder needs to be sealed, and

b) the temperature at which readings are taken needs to be closely controlled.

Currently, TTI has only tested one geomembrane, that being TYPAR, a Dupont product. Any extensive testing of geomembranes would require analysis of several different types and several different levels of geomembrane tension to simulate in-service conditions.

Also, there is a scarcity of data regarding how strong a geomembrane should be. The strengths required will clearly be application specific, i.e. vertical as opposed to horizontal moisture

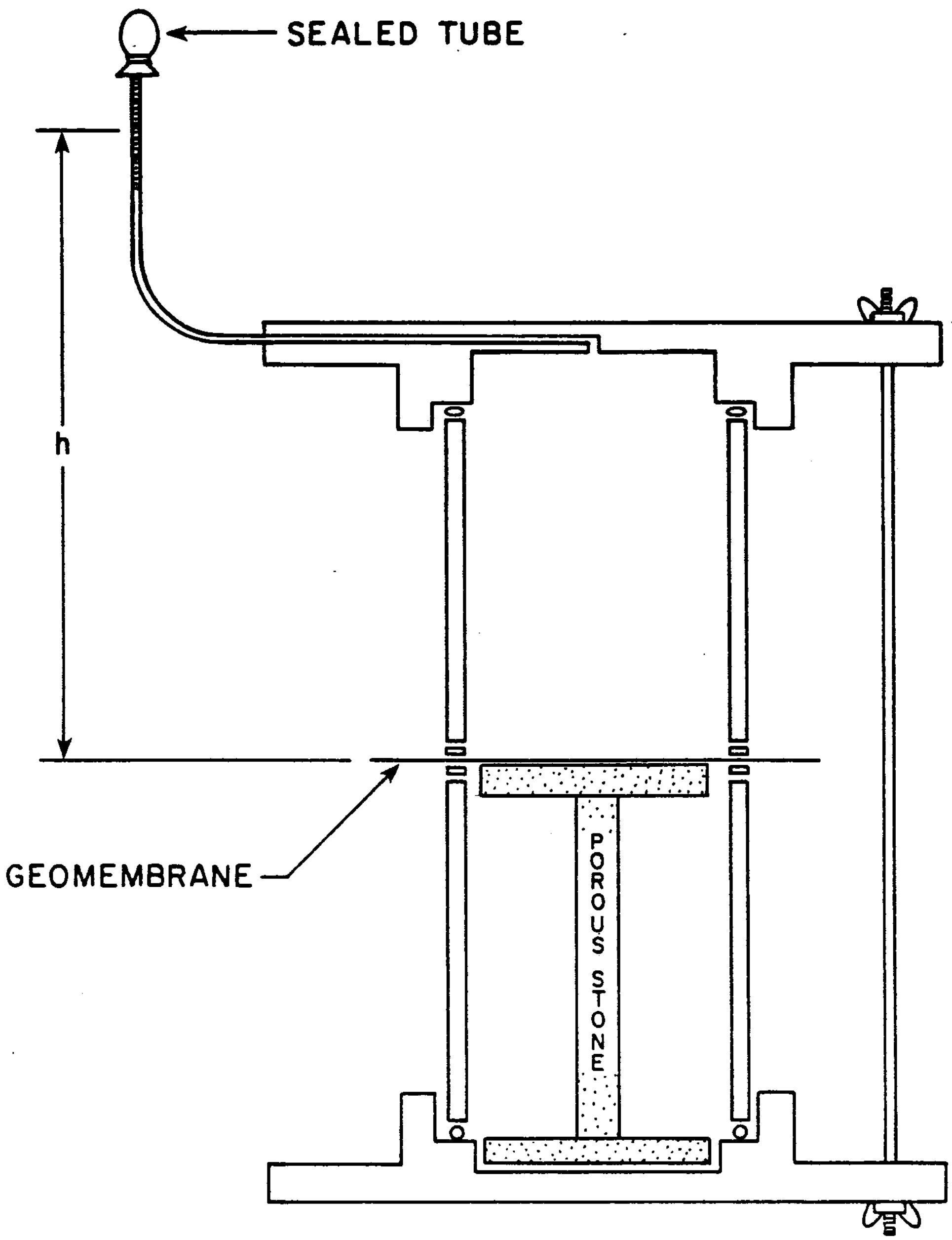


Figure 7.1. Cross-section Detail of TTI Geomembrane Permeameter

barriers.

7.4 Field Applications

Geomembranes can be considered in the following three highway applications.

Vertical Moisture Barriers (Figure 7.2)

This technique has been used very successfully by District 15 (3) to minimize problems associated with expansive clays. The geomembrane stabilizes the moisture content of the expansive clay, thus reducing the pavement roughness attributed to the shrinking or swelling of this subgrade layer.

This application is currently being studied by Departmental and TTI research projects. Reference should be made to these study reports to get more detailed information. TTI is currently monitoring suction measurement both inside and outside the impermeable barrier as well as developing a design procedure to determine the required membrane depth.

This application is also being investigated in an extensive field study on an Interstate pavement in District 1.

Horizontal Moisture Barriers (Figure 7.3)

In this application, the geomembrane is placed on top of the moisture susceptible subgrade. District 15 has experimented with these horizontal barriers on General McMullen Drive, a high volume highway in San Antonio. The geomembrane was placed in 1976,

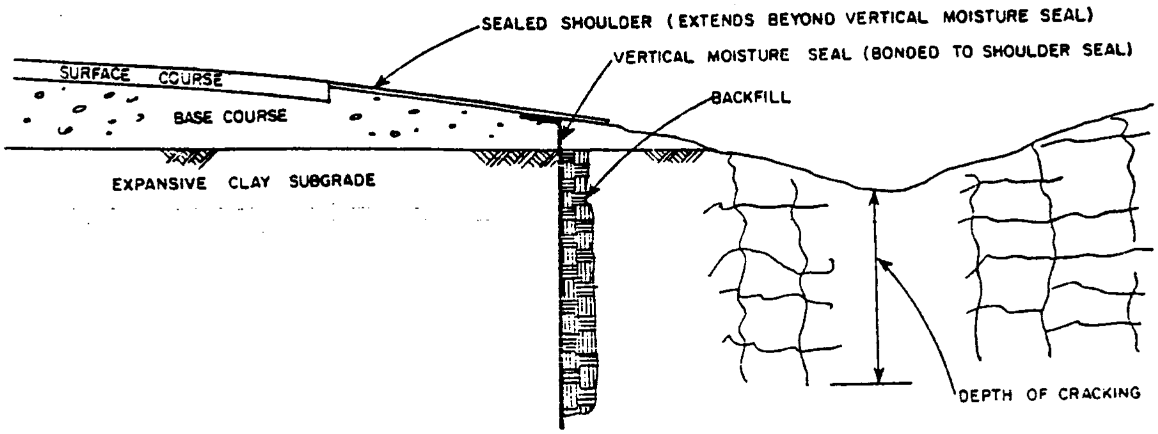
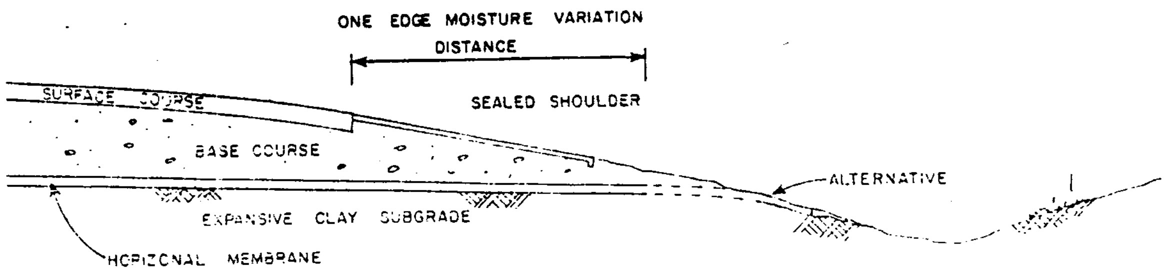
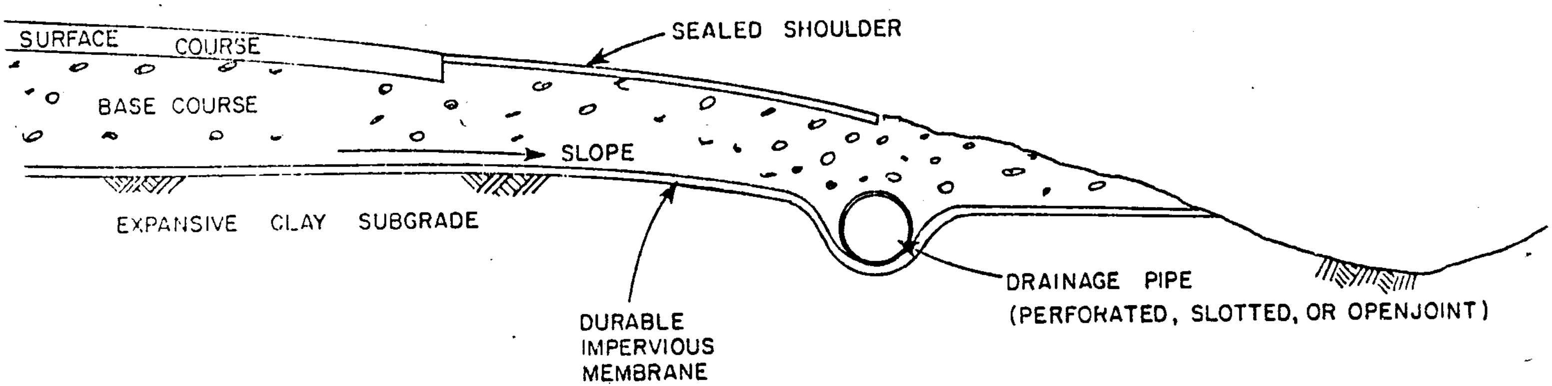


FIGURE 7.2 Vertical Geomembranes Used to Stabilize Moisture Content of Expansive Clay Subgrade



a) Simple Case



b) Membrane Plus Drainage Pipe

FIGURE 7.3 Horizontal Geomembranes Use to Waterproof Susceptible Subgrades underneath a thick pavement section consisting of 6 inches of flexible base, 8 1/2 inches black base, and 2 1/2 inches surface course. Monitoring has continued since then and results (34) to date indicate that more surface cracking is apparent in the control section than in the sections containing the geomembrane. The structural strength test results (Dynaflect) indicated that the stiffness coefficients of the pavement were higher in the geomembrane section, but the stiffness coefficients of the subgrade were lower for the geomembrane section. This indicates that the subgrade for the section containing the geomembrane is slightly weaker than the section without the geomembrane.

Other researchers (24) have observed that, in some instances, there is a tendency for moisture to build up under the impermeable barrier. Others have warned that impermeable horizontal barriers may also have problems if the subgrade undergoes any significant rutting. Water then entering from surface cracks may become trapped within the aggregate base layer.

Expansive clays do considerable damage to highways in several districts throughout Texas. The potential use of horizontal geomembranes to minimize this damage is clearly an area which should be further investigated. They have worked well in a thick pavement in District 15, how would they perform in a thin pavement? It is recommended that experimental projects be constructed to determine the performance of horizontal moisture barriers on thin pavements.

When experimenting with horizontal geomembranes, it is essential to ensure that any moisture entering through surface cracks is able to escape from the base course. The permeability of the base course should, therefore, be high enough to ensure that little water is trapped. This gives the department the opportunity to work with open graded base course which have been reported to have worked well elsewhere (Arkansas), and which are locally available in several districts in East Texas. Indeed several districts could produce lower cost base courses if there were no requirement to add fines, for stability, to an already open graded material that is an ideal drainage layer.

Other construction difficulties exist with horizontal moisture barriers. It is clearly essential to minimize the puncture damage during the compaction operation. This can be achieved by placing a thin layer of sand over the geomembrane before placing the base course. Furthermore, the geomembrane should be extended beyond the edge of the pavement surface to prevent edge infiltration and subsequent edge failure.

Interceptor Drains (Figure 7.4)

In situations where excessive ground water flow will be a problem. Geomembranes may be used to line interceptor drains to ensure water gets channeled into the drainage system rather than passing through the pavement structural layers.

7.5 Selecting a Geomembrane

In the literature search, very little information was found on specifying and selecting a geomembrane. It is thought that different

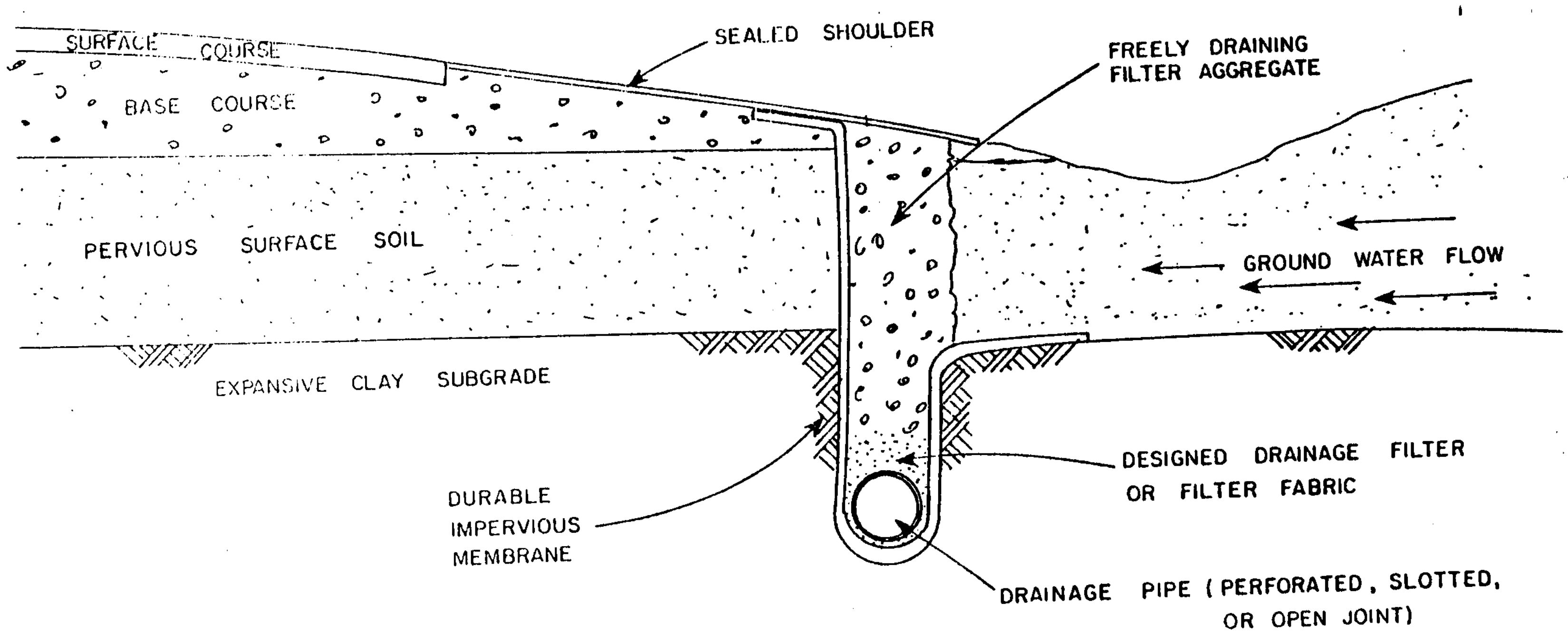


FIGURE 7.4 Interceptor Drains

properties are appropriate for different applications. For instance, the strength properties of geomembranes to be used as horizontal moisture barriers, undergranular base courses should be higher than those used as vertical moisture barriers.

Until more information becomes available, it is proposed that for vertical moisture barriers the minimum recommendation be those as given in Table 8.1. For geomembranes to be placed under base courses it is proposed that the minimum recommendation be those given in Table 8.3.

8. SUMMARY OF RECOMMENDATIONS

The aim of this report has been to summarize the literature on the testing of and specifications for geofabrics, and based on this survey to recommend a testing program for the Texas Department of Highways and Public Transportation. In this section of the report a summary is given of these recommendations.

8.1 Recommended Test Procedures

Below are listed a series of recommended test procedures. While some of the test procedures give values which can be used in design, i.e. the Tensile Test, others are simply index tests which have found acceptance in the testing community. It must be emphasized that there is no general agreement within the geofabric industry as to a standard set of tests and testing procedures. Because of this, a comprehensive set of recommended testing procedures is presented. While some of these tests may prove, with experience, to be unnecessary, it is felt that they should be included at this stage.

The recommended test procedures are as follows:

Primary Tests

1. The Wide Width Tensile Test (as recommended by ASTM D-35)

   This test is used to measure the geotextiles ultimate strength, strain at break and initial modulus. This test will become the national standard for testing the strength properties of geotextiles.

2. The Grab Strength Test (as recommended by ASTM D-35)

This has been the standard strength measuring test but it will, in the future, be replaced by the Wide Width Tensile Test. However, most of the current literature reports the grab test results and several sources have proposed specifications based on grab strength.

3. Trapezoidal Tear Test (as recommended by ASTM D-35)

This test is an index test used widely to compare the tear resistance of geotextiles.

4. Puncture Tests

The ASTM committee on geotextiles is not currently developing a puncture test. However, it has been noted (30) that most of the European agencies now have puncture resistance in their specifications. Several investigations have found that fabrics can fail in puncture either during construction or after a short time in service, so puncture resistance is a genuine concern.

The Texas Department of Highways and Public Transportation should consider developing a puncture test, perhaps based on the test currently being used by the New York State DOT (31).

5. Characterization of Hydraulic Properties

The following three tests are recommended to determine the hydraulic properties of geotextiles.

a. Apparent Open Size (ASTM - AOS Test) - This is the best available for determining geotextile pore size.

b. Constant Head Rate of Flow Test - Measuring the rate of flow under a constant head of 4 inches of water is recommended.

c. The Gradient Ratio Test (ASTM test) - The advantage of the AOS and Constant Head Permeability Test is that they are both quick tests to carry out. However, they both have series flaws and neither give any indication of long term performance. The validity of the AOS test result for nonwovens is still the subject of much discussion. The alternative to these tests is the Gradient Ratio Test which is strongly recommended. It is the only lab test which can simulate long term geotextile performance, including clogging potential. The disadvantages of this test is that it is a long term test taking up to 1000 hours for certain geotextile/soil combinations.

6. Flexibility Requirements

A simple flexibility/drapeability test is required to ensure that the geofabric can be readily installed. This is usually achieved by specifying that the fabric, when placed on a spherical ball (or suitable shape), conforms to that shape without breaking or cracking. The current Texas flexibility test used by the Highway Department is thought adequate for this purpose.

7. U.V. Resistance

To permit reasonable construction practices, the ASTM Xeon Weathereometer test is recommended.

Secondary Tests

These tests are currently considered of lesser importance than the primary test procedures just described.

1. Burst Strength (ASTM Mullen Burst)

   It is generally thought that is a fabric has a high tensile strength then it will have a high burst strength. It should therefore be possible to obtain high burst strength by specifying high tensile strength.

2. Creep Test (No test available)

   This test is of importance when geotextiles are being used in reinforcing applications, such as in landfills and in high deformation pavements. Creep testing of geotextiles is in the early stages of development. No standard test apparatus or procedures are available.

8.2 Tentative Geotextile Specifications

The recommendations presented in the earlier sections of this report are summarized here without discussion. There are two general classes of specification, a) general and b) application specific.

The general recommendations are suggested as the minimum to permit reasonable construction practices. These general recommendations are presented in Table 8.1.

Application specific recommendations are suggested when a given application requires geotextile characteristics more restrictive than the general recommendations. These are added to the general recommendation and replace them when they conflict. The application specific recommendations are as follows.

- Drainage Applications (Table 8.2). This is where the geofabric is to be used in drains to replace a graded granular filter.

- Under Base Courses (Table 8.3). Whenever a geotextile is to be placed underneath a base course for separation and/or reinforcing application the specification listed in this table are recommended. Horizontal Moisture barriers (geomembranes) can use the same strength specifications, ignoring the permeability requirements.

- Silt Fencing (Table 8.4).

8.3 Recommended Geofabric Applications

There is enough evidence from experimental projects conducted in Texas and elsewhere to conclude that geofabrics do offer some cost-effective alternatives to the highway designer. It is strongly recommended that, to complement any laboratory testing program that the department might undertake, some carefully controlled field experiments be conducted to determine the short and long term performance of geofabrics.

Below are listed some applications for geomembranes (impermeable) and geotextiles (permeable) which should prove to be cost-effective. Several of these are currently being investigated by the department, the others should be included in future experimental projects.

Recommended Geomembranes (Impermeable Geofabrics) Applications

A. Vertical Moisture Barriers. The geomembrane is used to minimize damage caused by swelling clays by stabilizing the moisture content of the subgrade. Reference should be made to the experimental projects in District 15 (3,32) and in District 1.

B. Horizontal Moisture Barriers. District 15 (34) has reported some success with this application on a thick heavily trafficked urban section of pavement. There is a need to determine if similar success can be obtained in other regions of the state and with thinner pavements. In this application the base course must be constructed with high enough permeability to ensure adequate drainage of surface infiltration. Open graded base courses have been reported to work well in other states and this possibility should be examined in Texas.

Horizontal Moisture barriers should be regarded as experimental at this stage. There have been some reports (27) of moisture being trapped under the membrane. Nevertheless, the opportunity of reducing damage to pavements by protecting the moisture susceptible subgrade needs to be further investigated.

Recommended Geotextiles (Permeable Geofabrics) Applications

A. Separators. In major reconstruction/strengthening of thin pavements with granular base, "weak spots" in the subgrade often become visible by some form of rapid failure of the structure. Similarly areas of high water table have often manifested themselves as troublesome maintenance spots. It is recommended that the geotextile be used as a separator between the subgrade and aggregate base in both cases.

When new aggregate base material is to be used to strengthen an existing pavement, geotextiles can again be used to separate the new from the existing base material.

B. Separators/Reinforcement. On pavements constructed on soft subgrades (CBR < 5, Texas Triaxial Class > 4.6) geotextiles should be considered for use as separators between the base and subgrade layers. If large deflections are also present, then the geotextile may also act to reinforce the section.

C. Drainage. In situations where subsurface drainage is a problem (gap graded soils, fine silty soils, high water table) geotextiles may be used to minimize the use of aggregate filters and provide economy in construction.

D. Reinforcement. As mentioned in Section 5 of the text it is doubtful that any significant reinforcing benefits could be achieved with currently available geotextiles. However, this is a dynamically changing area, new materials such as high modulus grids are now becoming available. Some manufacturers have also developed a lay-down machine which can pretension the grid prior to placing the next layer.

Once these grids become available in Texas, they should be investigated to determine if they can strengthen granular base courses.

Table 8.1

General Recommendations

Suggested Test	Limit	Test Procedure
Tensile Strength		
a) Grab Test	75 lb.	ASTM D1682
b) Wide Width Test	No data available	ASTM*
Minimum Elongation at Failure		
a) Wide Width Tensile Test	20%	ASTM*
Minimum Tear Resistance		
a) Trapezoidal Tear Test	50 lb.	ASTM D2263
Durability		
a) Xeon-Weatherometer	85% of original strength	ASTM G-26
Flexibility	Conforms to fixed shape	Texas Current test method

*Soon to be made a standard test by the Geotextile Committee (D-35)

Table 8.2

Proposed Limits for Drainage

Suggested Test	Limit	Test Procedure
Gradient Ratio	< 3	ASTM*
Piping Resistance	$O_{90} < D_{85}$ Soil	ASTM AOS Test
Permeability	$K_g > K_s$	Constant Head Permeability Test
	$O_{90} > D_{15}$ Soil	ASTM AOS Test

*As recommended by ASTM Committee D-35

Table 8.3

Proposed Limits for Geofabrics Under Base Courses

Suggested Test	Limit	Test Procedure
Minimum Tensile Strength		
a) Grab Test	200 lb.	ASTM D1682
b) Wide Width Test	No data available	
Minimum Tear Strength	100 lb.	Trapezoidal Tear ASTM D-2263
Minimum Puncture Strength	No data available	
Minimum Burst Strength	$\frac{\text{Burst Strength}}{\text{Pressure on Subgrade}} > 1.0$	ASTM D-751
Modulus	From Grab Test of Wide Width Tensile Test (WWTT) - Designer Judgement - Higher is desirable	
Elongation	Min. Failure 20%	Grab Test or WWTT
Rate of Water Flow	No data available	
Reverse Sieving	$O_{90}<D_{85}$ Soil $O_{90}>D_{15}$ Soil	ASTM AOS Test for Procedure
Gradient Ratio Test	< 3	Corps of Engineers (Calhoun)

*As recommended by ASTM Committee D-35

Table 8.4

Proposed Limits for Silt Fencing

Suggested Test	Limit	Test Procedure
Minimum Tensile Test		
a) Supported by wire	30 lb/in	ASTM Wide Width Tensile Test*
b) Supported by post only	200 lb/in	
Minimum Tear Resistance		
a) Trapezoidal Tear	100 lb.	ASTM D-2263
Minimum U.V. Resistance		
Xeon Weatherometer	85% strength after 500 hrs exposure (6 month life) 3000 hrs exposure (3 year life)	ASTM G-26
Minimum Initial Permeability	0.4×10^{-2} in/sec	Constant Head
Pore Size	$70 \leq$ AOS ≤ 100	ASTM AOS Test

*As recommended by ASTM Committee D-35

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APPENDIX A

EXPERIMENTAL GEOFABRIC PROJECTS IN TEXAS

In this appendix a brief description will be given of the nine geofabric projects which have been constructed by the Texas SDHPT. The location of these projects is shown in Figure A.1. Where possible, reference should be made to available reports for a more complete discussion, particularly the reports describing the San Antonio projects (3), (32), and (34).

However for several of these projects very little published information is available. Further information can then be obtained by either a) contacting the District personnel or b) contacting D-10 Research in Austin.

For each of the nine projects, the contact person within the District is listed, and a brief description of the project is given. When the geofabric has been used underneath the base course, the available structural evaluation data (dynaflect deflections) is summarized. The nine projects are as follows.

1) Vertical Moisture Barrier on Loop 410, San Antonio (Contact M. L. Steinberg, District 15)

In March 1979, a 1/2 mile section of Interstate Highway Loop 410 was rehabilitated by releveling and placing a geomembrane (Typar) vertically at the edges of the outside and inside shoulders. This major highway had become exceedingly rough, primarily due to movements within the expansive clay subgrade (Atterberg limits - Liquid limits

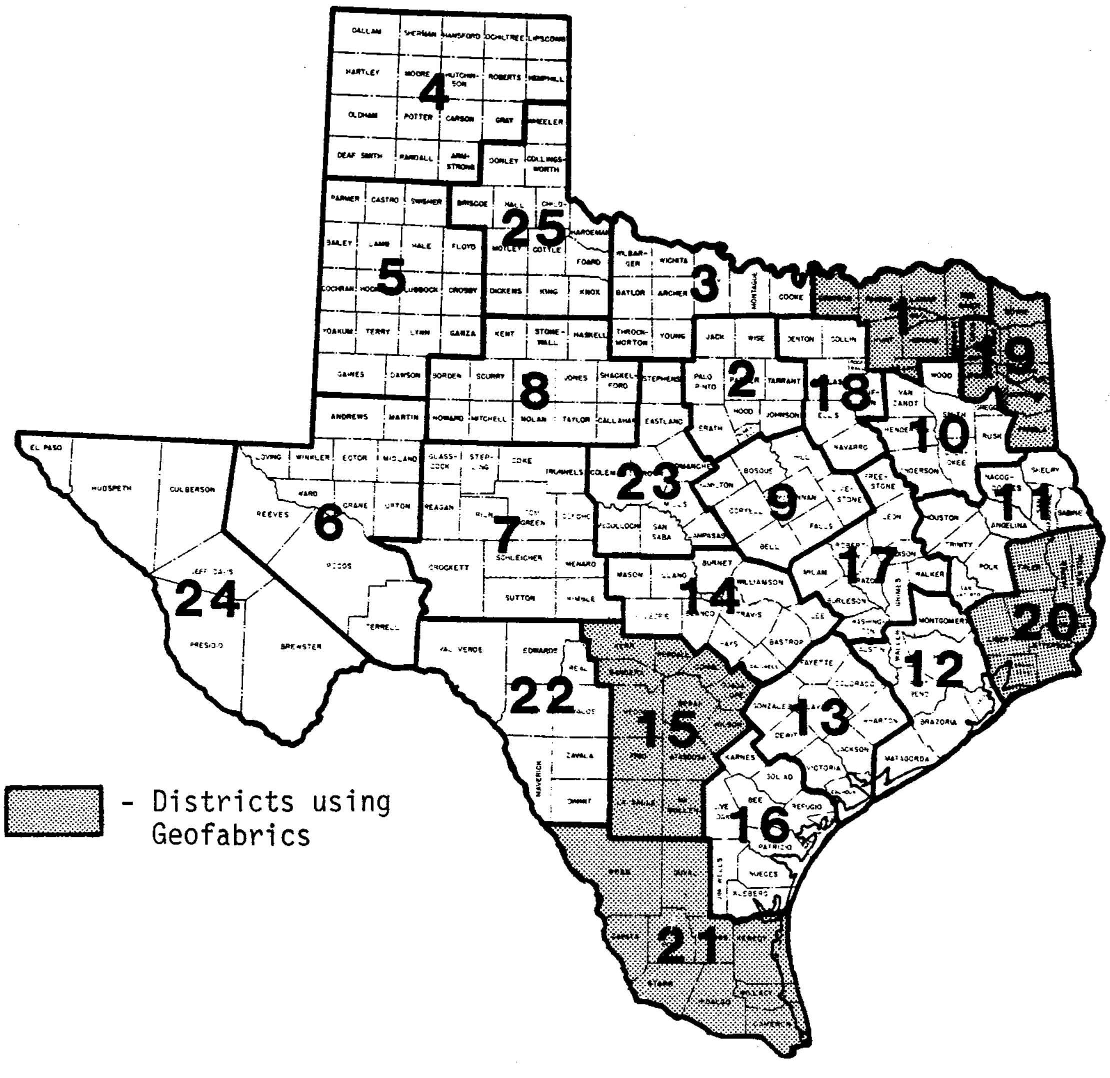

Figure A.1 Texas Districts using geofabrics in pavements

50 to 79, plasticity index 28 to 48).

Monitoring, with photologging, Mays Ride, and moisture sensor readings, has continued since rehabilitation. It has been reported that the protected section is smoother, has less cracking and has needed less level-up than the unprotected section.

2) Vertical Moisture Barrier on IH 37, San Antonio (Contact M. L. Steinberg, District 15)

This highway had experienced a substantial swelling clay movement since its construction in 1968. A level-up, asphaltic concrete finish course and a deep vertical moisture barrier were installed in May 1980. The Typar geomembrane was place 8 feet deep in trenches at the edge of the pavement.

Monitoring, including photologging, Road Roughness, and Moisture sensor readings, has continued since construction. The Mays ride reading indicates that the protected section is smoother than the control section. Furthermore readings on the moisture sensors indicate that the moisture content of the protected subgrade has remained relatively constant, as opposed to the large moisture changes in the unprotected section.

3) Vertical Moisture Barrier Demonstration Project on IH 30 near Greenville, District 1 (Contact Bob Long, District 1)

This section was constructed in mid-1984. The aim is to compare the performance of vertical moisture barriers (geomembrane versus pressure lime injection) in controlling pavement roughness caused by expansive clay.

Monitoring of this section has just begun. Soil Suction, Deflection, and Roughness measurements will be made at regular intervals.

4) Horizontal Moisture Barrier on General MacMullen Drive in San Antonio (Contact M. L. Steinberg, District 15)

In 1976, the Department reconstructed a major arterial built upon swelling clay. An impermeable membrane (Typar) was placed over the subgrade on top of which was placed a 6 inch Flexible Base, 11 inches Black Base, and 1 1/2 inches Wearing Surface.

Monitoring, including field elevations, visual observations, dynaflect observations, photologging, and profilometer, is performed at regular intervals. In general it was found that the geofabric sections were smoother and had less cracking than the control sections. Of the six geofabric sections, the maximum decrease in PSI between 7/81 and 6/82 was 0.27 (3.86 to 3.59) and the average decrease was less than 0.10.

Deflection data was collected on 1-22-81 and 3-31-82. The summary results are tabulated in Tables A1 and A2.

In 1981 the average maximum dynaflect deflections (W1) were 0.674 mils for the control section and 0.854 mils for the fabric treated section, and the standard deviations were 0.166 and 0.138, respectively. A "t-test" of this data indicated that the sections containing the geotextiles had higher deflections than the control section. From inspection of tables A1 and A2, in general the sections

TABLE A1. Summary Dynaflect Deflections Data Collected on General MacMullen Drive in San Antonio (1/22/81)

Lane		W1	SCI	AS2	AP2	S	MD
L	Control	0.999	0.102	0.200	0.810	0.760	0.022
	Fabric						
	Control	0.560	0.060	0.220	0.780	0.740	0.016
M	Control	0.752	0.070	0.210	0.850	0.790	0.017
	Fabric	0.681	0.047	0.200	0.930	0.830	0.015
	Control	0.580	0.052	0.210	0.850	0.790	0.013
N	Control	0.710	0.040	0.190	1.010	0.810	0.015
	Fabric	0.812	0.039	0.180	1.070	0.860	0.018
	Control	0.531	0.046	0.220	0.870	0.810	0.012
T	Control	0.589	0.051	0.210	0.860	0.788	0.013
	Fabric	0.854	0.060	0.190	0.920	0.840	0.019
	Control	0.759	0.077	0.210	0.800	0.800	0.017
S	Control	0.649	0.057	0.210	0.860	0.790	0.015
	Fabric	0.859	0.060	0.190	0.930	0.840	0.019
	Control	0.685	0.051	0.200	0.900	0.820	0.015
R	Control	0.795	0.067	0.200	0.850	0.800	0.018
	Fabric	1.100	0.080	0.180	0.900	0.840	0.025
	Control	0.909	0.093	0.200	0.850	0.800	0.020

W1 = Deflection at geophone 1
SCI = Surface curvature index (W1 minus W2)
AS2 = Stiffness coefficient of the subgrade
AP2 = Stiffness coefficient of the pavement
S = Spreadability
MD = Maximum deflection (Benkelman)

TABLE A2. Summary Dynaflect Deflections Data Collected on General MacMullen Drive in San Antonio (3/31/82)

Lane		W1	SCI	AS2	AP2	S	MD
L	Control	1.017	0.112	0.200	0.790	0.740	0.023
	Fabric	0.966	0.072	0.190	0.900	0.780	0.022
	Control	0.719	0.060	0.200	0.890	0.750	0.016
M	Control	0.749	0.052	0.200	0.950	0.790	0.017
	Fabric	0.747	0.034	0.180	1.090	0.830	0.017
	Control	0.614	0.038	0.200	0.980	0.790	0.014
N	Control	0.725	0.048	0.190	0.980	0.800	0.016
	Fabric	0.848	0.039	0.180	1.090	0.830	0.019
	Control	0.591	0.037	0.200	0.990	0.800	0.013
T	Control	0.670	0.041	0.190	0.980	0.790	0.015
	Fabric	0.923	0.048	0.180	1.030	0.820	0.021
	Control	0.745	0.046	0.190	0.990	0.810	0.017
S	Control	0.690	0.030	0.180	1.100	0.800	0.015
	Fabric	0.881	0.050	0.180	1.000	0.820	0.020
	Control	0.756	0.042	0.190	1.010	0.810	0.017
R	Control	0.891	0.074	0.190	0.850	0.760	0.020
	Fabric	1.136	0.099	0.190	0.840	0.770	0.026
	Control	1.024	0.124	0.200	0.740	0.730	0.023

W1 = Deflection at geophone 1
SCI = Surface curvature index (W1 minus W2)
AS2 = Stiffness coefficient of the subgrade
AP2 = Stiffness coefficient of the pavement
S = Spreadability
MD = Maximum deflection (Benkelman)

containing the geotextile had lower subgrade stiffness and higher pavement stiffness.

5) Horizontal Geotextile (Permeable) on R.R.3 near Bonham, District 1 (Contact Bob Long, District 1)

This lightly trafficked recreational road had become extremely rough primarily due to the measurements of the expansive subgrade. Several sections of this road had PSI values of less than 1.0. The pavement structure consisted of a surface treatment, six inch flexible base layer on top of the subrade.

In September 1983, the base course was bladed off, and the subgrade was leveled and recompacted. A permeable geotextile (Mirafi 500X) was placed on the subgrade and the existing base course was replaced followed by a surface treatment. A control section was also built.

Monitoring to date has included visual evaluation, Mays Ride evaluation, and Dynflect.

The average dynaflect reading for the experimental and control sections are shown below.

Description	# Readings	W_1	W_2	W_3	W_4	W_5	AS2	AP2
Experimental (Geotextile)	13	2.32	1.36	0.77	0.45	0.32	0.25	0.63
Control	14	2.31	1.31	0.76	0.45	0.32	0.25	0.58

where W_1 through W_5 are the dynaflect sensor readings (mils) and AS2 and AP2 are the stiffness coefficients of the subgrade and pavement.

The above data were collected approximately 2 months after construction. Currently there is no statistical evidence to suggest that the geotextile is strengthening this pavement. However, monitoring of this section is continuing to determine if any long-term benefits are realized.

6) <u>Horizontal Geotextile on Farm-to-Market Road, District 1</u> (Contact Bob Long, District 1)

While cement stabilizing the base of a Farm-to-Market road in District 1, a very wet spot in the subgrade was located. The problem was traced to a spring beneath the road. This soft subgrade presented a difficult construction problem.

To overcome this problem, the subgrade was undercut to the ditch line. A Mirafi 500X geotextile was laid and 4 feet of subgrade was replaced. Construction continued without a problem, and this 1200 foot section has performed well.

7) <u>Horizontal Geotextile Used to Reinforce an Approach Embankment for a new Bridge Over the Neches River</u> (Contact Bill Potter, District 20)

A new bridge is planned to be constructed over the Neches River on SH 87 between Port Arthur and Orange. The soil condition on both approach roads is very poor, there is a thick clay layer 20-40 feet deep. These "marshy" conditions presented a major construction problem. New fill was being lost to the underlying marsh and it was difficult to get any equipment on the site.

APPENDIX B

ANALYZING GEOFABRICS IN PAVEMENT STRUCTURES

1. Introduction

One task of this project was to review existing analytical computer programs for modeling the effect of geofabrics on pavement structure. If such a program is available, and it can adequately model the soil-geofabric interaction, then it will be an excellent tool for developing a rational geofabric reinforced pavement design procedure.

After reviewing the available computer software, it was concluded that the program SSTIPN was the best available for analyzing geofabrics in pavement structures. This program and the pavement modeling technique will be described in this Appendix.

2. Reinforcing Mechanism

Reinforcing mechanisms of high deformation systems (haul roads and construction access roads) have been well documented (7,8, 20,23,25,40). However, reinforcing mechanisms applicable to low deformation systems (highway pavements) are somewhat uncertain. In a high deformation system, the primary reinforcing functions are thought to be a) membrane action and b) lateral constraint of base material as discussed in Section 5.2 of the main report.

It has been reported, with current fabrics and construction techniques, that rut depths of one inch or more are required for

To separate the poor subgrade from the new fill material, a geotextile was laid. Two geotextiles, Mirafi 600X and a Phillips woven were used on this job. The geotextile permitted the construction to proceed by providing a working table. Wick drains were installed in the thick clay layer. It has been predicted that 90% of the expected settlement of this site will occur within 3 years.

This is a major operation and the geotextile fabrics are ideally suited to this application.

8) Horizontal Geotextile Under Heavily Trafficked Thin Pavement in District 19 (Contact Elvin Rousseau, District 19)

In May 1981, a section of thin flexible pavement was constructed with the Typar nonwoven geotextile placed between the subgrade and base course. Site conditions in this area were reported as poor, with considerable moisture in the subgrade.

This highway was subjected to very heavy traffic by aggregate haulers. Within two months after opening to traffic, several severe edge failures were reported. Maintenance forces dug out the failed areas and noted that both base course and subgrade were in reasonable condition. They concluded that the edge failures were caused by slippage at the base-fabric-subgrade interface.

9) Horizontal Geotextile Under a Base Course, District 21 (Contact Homer Guitteriz, District 21)

A section of SH 186 was reconstructed shortly after Hurricane Allen hit South Texas (early 1981). This section of highway close to

Port Mansfield was built on a very poor subgrade soil, had a high water table, and was prone to flooding at high tide.

The new pavement structure consists of 8 inches of lime treated subgrade, 8 inches of granular base, and approximately 1.5 inches of hot-mix asphaltic concrete. A Mirafi geotextile (500X) was placed at the following location along the westbound lane.

Station Location	Geotextile Placement
620+15 to 622+00	Shoulder + 2 feet of travel lane
745+00 to 751+00	Shoulder + entire travel lane
763+48 to 767+50	Shoulder + entire travel lane
767+50 to 771+00	Shoulder + 2 feet of travel lane
771+00 to 783+46	Shoulder + entire travel lane

At several locations, the geotextile was placed under the shoulder and entire westbound travel lanes. At other locations, the geotextile was extended only 2 feet into the travel lane.

After 3 years of performance, very little distress has been found in either the eastbound or westbound lanes.

The dynaflect deflection results from these sections are difficult to analyze because, for some unknown reason, the deflection measurements are notably higher over the entire westbound lane (including fabric) than in the eastbound lane (no fabric). A summary of the collected data is shown in Table A3.

At a first glance, these results would indicate that the geotextile has had a detrimental effect on pavement strength. However, this is difficult to substantiate because of the fact that

TABLE A3. Summary of Dynaflect Deflection Data for Geotextile Project on SH 186 in District 21

Type of Treatment	Location	Average Dynaflect Deflection						
		W1	W2	W3	W4	W5	AS2	AP2
Fabric (Shoulder+2ft of lane)	620+15 to 622+00	1.85	1.21	0.77	0.55	0.42	0.24	0.41
Non Fabric		1.08	0.86	0.71	0.53	0.41	0.23	0.57
Fabric (Shoulder+ entire lane)	745+00 to 751+00	2.00	1.40	0.95	0.67	0.50	0.22	0.43
Non Fabric		1.20	1.02	0.84	0.64	0.51	0.20	0.70
Fabric (Shoulder+ entire lane)	763+48 to 767+50	1.71	1.21	0.86	0.61	0.47	0.22	0.42
Non Fabric		1.26	1.06	0.87	0.65	0.52	0.21	0.65
Fabric (Shoulder+2ft of lane)	767+50 to 771+00	1.65	1.12	0.84	0.63	0.49	0.23	0.40
Non Fabric		1.15	0.98	0.84	0.65	0.52	0.21	0.66
Fabric (Shoulder+ entire lane)	771+00 to 783+46	1.69	1.05	0.72	0.52	0.40	0.24	0.37
Non Fabric		1.16	0.98	0.80	0.61	0.47	0.21	0.66
Eastbound Lane	Entire 8-mile section	1.63	1.15	0.84	0.61	0.47	0.23	0.47
Westbound Lane		1.38	1.13	0.90	0.67	0.52	0.21	0.63

AS2 and AP2 are calculated stiffness values for the subgrade and pavement respectively. The higher the value the stiffer the value.

the lane containing the fabric (westbound) had a higher deflection than the non-fabric lane (westbound) whether the fabric was present or not.

This section is worthy of further monitoring. Further deflection measurements need to be taken to clarify these confusing early results.

membrane action to have a significantly reinforcing effect in a pavement. Such deep ruts are unacceptable for high speed highways and indeed in recent condition surveys deep rutting is not frequently found in Texas pavements. Therefore, for Texas pavements this leaves lateral confinement of base material as the only major reinforcing mechanism to be considered in fabric reinforced highway pavements. Lateral confinement is a function of:

1. the state of stress in the pavement
2. the frictional characteristics of the aggregate-fabric and fabric-subgrade interfaces
3. the thickness of the aggregate base material above the fabric.

3. Method of Analysis

The SSTIPN finite element program is ideally suited to model a geofabric reinforced pavement. SSTIPN uses an iterative process to model the nonlinear and stress-dependent stress-strain properties of a soil using the procedures developed by Kulhaway, Duncan, and Seed (41). Other important features of the SSTIPN program include (1) interface elements for modeling of the geofabric-aggregate and geofabric-soil interfaces, (2) structural elements for modeling the geofabric (these elements are not capable of resisting bending forces), and (3) no-tension analysis of cohesionless materials.

The geofabric interfaces are modeled using special interface elements illustrated in Figure B.1. In this figure, four interface elements are shown, one above and one below each geofabric element.

The interface elements above the geofabric are used to model the frictional characteristics of the aggregate-geofabric interface. Similarily, the interface elements below the geofabric model the subgrade-geofabric frictional characteristics. The normal springs are assumed to be constant and linearly elastic in compression. The shear springs are represented by a hyperbolic model representing the stress dependent properties of the interface.

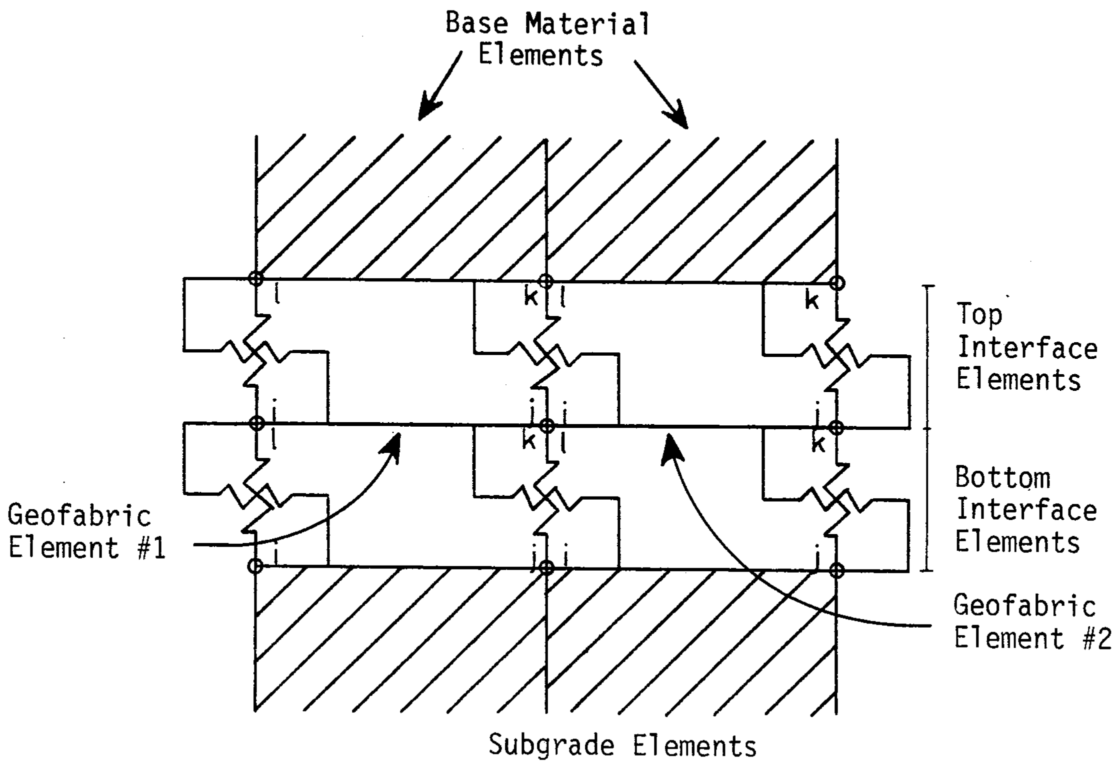

Figure B.1. Soil-Fabric Finite Element Interface Model

The required interface material properties can be determined in a laboratory by performing direct shear tests on aggregate-geofabric and soil-geofabric interfaces. By varying the normal stress applied to the interface, the constants for the Mohr-Coulomb Failure Law can be found.

Mohr-Coulomb Failure Law

$$\tau_{max} = C_a + \sigma_n \tan \delta$$

where

C_a = adhesion between the interface materials

δ = friction angle between the interface materials

σ_n = normal stress

This test has been performed by Barksdale (38,40) with good success. The computer program SSTIPN uses this equation as the maximum shear stress which can be allowed to develop at the interface before slippage occurs.

The accuracy to be expected from the finite element analysis is dependent on how well the material properties used correspond with those in the field. For this analysis, base and subgrade modulus values have been back-calculated from dynaflect deflections. Data from direct shear test analyses acquired from the Georgia Institute of Technology were used to model the interface material properties. Physical properties of the geotextiles had to be taken from manufacturer's literature which is undesirable due to variations in the way modulus values can be recorded.

4. Conclusions and Recommendations

Efforts are currently underway to use SSTIPN to analyze the dynaflect deflection data collected on geofabric projects around Texas. Although this analysis is not yet complete, the following important points should be mentioned.

1. Dynaflect measurements from District 1 suggest that the geotextile may reduce residual stresses in the pavement. If this proves to be true, development of ruts and alligator cracks in the wheel path may be delayed.
2. A number of failures have been reported in geotextile reinforced pavements, while in other installations neither benefit nor impairment of the pavement due to the geotextile presence can be substantiated.

In order to learn more about the effects geofabrics have on a pavement's structural behavior, the following are recommended:

1. That the SDHPT collect falling weight deflectometer data on experimental fabric reinforced pavements in Texas. The dynaflect load of 1000 lbs. is very light. It is thought that by using the FWD and by gradually increasing the load, then the benefit of geofabrics should be readily determined. It may well be that under heavy loads, such as those applied under truck loading, that the geofabric significantly influences pavement performance.
2. Perform wide-width tensile tests on geotextiles which have been used in Texas pavements. This will be used to determine initial modulus values for computer analysis.
3. Initiate laboratory tests to determine frictional characteristics of geofabric-soil and geofabric-base interface.
4. A finite element analysis of experimental test sections using data from (1) and (2) above.