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Effect of Fabric Properties on the Performance and Design of Aggregate-Fabric-Soil Systems

Influence des textiles sur les performances et le dimensionnement de systèmes: agrégats-textile-sol

The effects of fabric properties on performance and design of aggregate-fabric-soil (AFS) systems are discussed and quantified where possible. Primary emphasis is placed on examining the effect of mechanical properties on performance and design using data obtained from the pertinent literature and a study conducted at Georgia Tech. In general, it was found that the fabric modulus was the single most important fabric property governing the behavior of the AFS system. The use of a geotextile in an aggregate soil system leads to improved system performance (e.g. longer service, reduced rutting) or alternately, a 25-40 percent reduction in the amount of required aggregate.

Quantitatively, the amount of this performance improvement (aggregate reduction) resulting from the use of a particular fabric correlates well with the modulus (resistance to stretch) of the fabric used. High modulus fabrics result in less rutting or better system performance than those with lower modulus.

Les influences des propriétés textiles sur la performance et sur l'étude des systèmes agrégat-tissu-sol (AFS) sont discutés, et, dans la mesure du possible, quantifiés. On souligne l'examen de l'influence des propriétés mécaniques sur le fonctionnement et sur l'étude, en employant les données obtenues de la bibliographie et d'une étude faite à Georgia Tech. On a conclu, en générale, que le module du tissu est la propriété la plus importante pour le fonctionnement du système AFS. L'emploi d'un géotextile dans un système agrégat-sol mène à un fonctionnement amélioré (e.g. fonctionnement prolongé), moins d'ornières, ou, comme alternative, une diminution de 25 à 40 pourcent de la quantité requise d'agrégat. L'amélioration qu'apporte l'emploi du tissu spécifique au fonctionnement du système (diminution d'agrégat) présente une bonne correlation avec le module d'élasticité (résistance à la traction) du tissu employé. L'emploi du tissu à module élevé, comparé à celui d'un module moins élevé, donne une réduction d'ornières et un fonctionnement meilleur du système.

INTRODUCTION

The use of geotextiles or fabrics in high deformation, low volume road construction has become increasingly popular over the last two decades. In this application the fabric is used in conjunction with a locally available aggregate such as crushed stone, quarry "shot rock", sand, sea shells, etc. to develop a structural support layer.

The benefit offered by the fabric is attributed to reinforcement and separation and is most often measured in terms of improved system performance or, alternately, in terms of reduced aggregate thickness requirements (1). Figure 1 shows the effect of fabric on aggregate road performance. For low strength support conditions where fabrics appear most beneficial, a reduction in aggregate thickness in the range of 25 to 40% can be made normally when fabric is installed between the aggregate and soil (1).

Selection of fabrics and establishment of use specifications for particular field applications is often difficult for the potential fabric user due to a general lack of knowledge relative to the impact of fabric properties on potential performance. Since many existing design methods for aggregate roads are (a) fabric specific, (b) unclear as to basic assumptions, (c) empirical and (d) unable to predict performance, the impact of various fabric types (and hence properties) on performance and economics of the fabric reinforced aggregate road is not readily apparent.

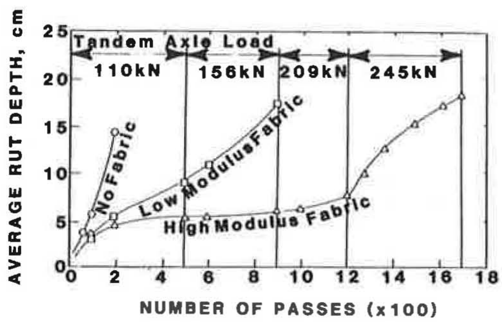

Fig. 1 Rut Depth as a Function of Vehicle Passes (From Ref. 5).

PURPOSE AND SCOPE OF PAPER

The primary purpose of this paper is to quantify where possible, based on current literature and the results of a recent study, the effect of fabric properties on the performance and design of fabric reinforced aggregate roads or aggregate-fabric-soil (AFS) systems. Sources of data and information used to develop this paper include pertinent literature and the results of a study being conducted in the School of Civil Engineering at the Georgia Institute of Technology, Atlanta, Georgia, U.S.A.

GEOTEXTILES

General

For the purpose of this paper, the term geotextile or fabric will be used interchangeably and will adhere to the definition established by ASTM which says a "geotextile is any permeable textile used in conjunction with goetechnical materials as an integral part of a manmade project, structure, or system".

The geotextile market has increased dramatically in recent years as a result of new uses and new manufacturers. Available commercially is a wide range of man-made, synthetic fabrics ranging in type (woven and nonwoven), fiber composition (mainly polyester and polypropylene), basis weight and inherent properties. Undoubtedly more fabrics will become available in the future. Space limitations do not permit a detailed description and/or identification of all the geotextiles available commercially.

Fabric Properties

The degree of benefit offered by a fabric to the AFS system for its service life depends to a large extent on the inherent properties of the fabric used. Other factors such as subgrade strength, loading environment, and aggregate properties also have an important influence on the behavior and performance (rutting resistance) of the AFS system (1).

Specific properties of significance relative to the optimum use of fabrics in aggregate surfaced roads are numerous, although the exact contribution of each is largely unknown. Bell, et al. (2) have listed and discussed in detail a large number of fabric properties of apparent significance in the broad sense of geotechnical applications which include the following: Mechanical Properties -- strength, elongation, modulus, creep, stress relaxation, fatigue, tear resistance, cutting and abrasion resistance, friction; Hydraulic Properties -- permeability, filtering ability, clogging and blinding resistance, capillary siphoning; Durability Properties -- thermal, biological, chemical, and ultraviolet light stability.

The previous list of fabric properties is formidable. In a qualitative sense all may appear significant. However, the minimum, maximum or optimum level of each and the combined or interactive effect of these properties are yet to be fully understood and quantified. Even test methods to evaluate specific properties have not yet been universally accepted. As an example, mechanical properties of fabrics are often determined from mechanical tests on the fabric in isolation. When a fabric is placed in the AFS system, the fabric may behave in a substantially different manner because of the presence of aggregate and soil. Holtz (3) and McGown, et. al (21) report that the modulus of fabrics in soil may be 2-3 times the value in isolation. Complicating the situation even more is the fact that most fabrics are anisotropic, i.e. they have properties which depend upon orientation.

Bell, et al. (2) suggest that mechanical properties of fabrics may be the most significant for ground stabilization applications. Hydraulic properties probably have secondary importance. Dissipation of pore pressure created due to loading and settlement can be accommodated by most geotextiles. Furthermore, for typical AFS system applications, most geotextiles have adequate durability (e.g., thermal, biological, chemical, and ultraviolet stability).

BENEFIT MECHANISMS

Mechanisms by which a fabric improves the structural performance of the AFS system under repetitive vehicular loading have been discussed by several investigators and include basically two categories, reinforcement and separation.

Specific mechanisms that have been identified are:

A. Restraint Effect

Two types of restraint effect may occur in the AFS systems. The first, often referred to as subgrade restraint, is related to the reverse curvature of the fabric that develops outside the wheel path and the resultant induced downward pressure or apparent "surcharge" applied to the soil, Figure 2. Such an effect increases the bearing capacity or resistance to shear flow of the soil from the wheel path. A second type of restraint, called aggregate restraint, occurs when the aggregate particles at the soil-aggregate interface tend to move from under the loaded area but are restrained or confined due to the presence of the fabric (4). Modulus, strength, friction, creep (stress relaxation) and abrasion or puncture resistance of the fabric may be very important to this mechanism.

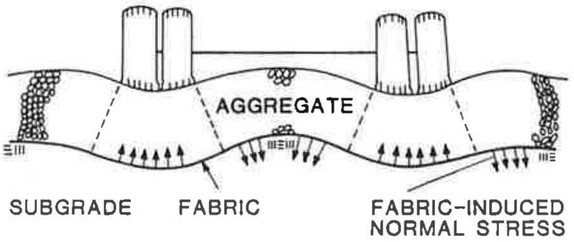

Fig. 2 Schematic of Aggregate-Fabric-Soil System.

B. Membrane Effect

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As the roadway undergoes large deformation, Figure 2, the fabric is stretched and develops in-plane tensile stress, the magnitude of which depends on fabric strain art and fabric modulus. A stress perpendicular to the plane of the fabric is induced, the magnitude of which at any point equals the in-plane stress divided by the radius of curvature of the fabric at that point. The net effect is a change in the magnitude of stress imposed on the subgrade (a reduction under the wheel load and an increase outside of the wheel path) and an increased confinement of the aggregate.

In order to develop fabric-induced stress, substantial vertical deformations, plus proper geometry, fabric anchorage and proper fabric mechanical properties are generally required. Fabric properties of modulus, strength, creep (stress relaxation), elongation-to-break and friction are important to this mechanism.

C. Friction and Boundary Layer Effect

Friction developed along the interface between aggregate-fabric and friction/adhesion at the fabric-soil interface create a "boundary-layer" or composite material of aggregate and soil immediately adjacent to the fabric. The composite material created should possess more favorable properties of ductility and tensile strength. Fabrics capable of developing high friction/adhesion appear to be desirable.

D. Local Reinforcement

Concentrated stresses due to imposed vehicular loading can cause a punching or local bearing capacity failure at the points of contact between the aggregate and subgrade. Use of fabric between the aggregate and soft soil will serve to distribute the load, reduce localized stresses and in general provide increased resistance to vertical displacement. Mechanical properties of modulus, strength, and puncture resistance appear important for this mechanism.

E. Separation

In the separation function, the fabric serves to prevent the fine-grained subgrade soil from pumping and intermixing with the coarse-grained aggregate material and thereby reducing its shear strength and stability. Depending on aggregate gradation, 10 to 20 percent additonal plastic fines can cause a substantial reduction in shear resistance (5,6).

Bell, et al. (2) have discussed extensively the function of separation provided by fabric. Basically two phenomena have been identified which must be mitigated if the separation function is maintained; these are subgrade pumping and subgrade intrusion. Pumping requires relatively high stress at the subgrade-fabric interface, free water, pumpable subgrade and a granular material open enough to allow entry of the fine material (if the fabric were not at the interface). In regard to the pumping phenomenon, Bell, et al. (2) conclude that "the theories of pumping and fabric influences (on pumping) are not well developed. They (theories) do not even show clearly the fabric properties which are important to prevent pumping". Bell, et al. (2) also state "There are however, numerous installations of fabrics..which indicate that many of the fabrics on the market today do effectively prevent pumping of subgrades".

With respect to the intrusion phenomena, the fabric serves to physically prevent the intermixing of the granular and subgrade material. Bell, et al. (2) state that in order to prevent intrusion, the fabric must not be punctured by the aggregate and must not fail by localized rupture. Furthermore, they state that fabrics will tend to prevent intrusion or pumping of the subgrade and that important fabric properties (although not quantified) include pore characteristics, friction, strength, puncture resistance and abrasion resistance.

From the previous discussion, it can be assumed that as long as a geotextile remains intact, few problems will be encountered relative to pumping and intrusion.

EFFECT OF FABRIC PROPERTIES ON SYSTEM PERFORMANCE

In the previous section, various mechanisms responsible for the benefits accruing from the use of fabric have been discussed. Possible mechanical properties necessary for the benefit mechanism have been suggested. However, quantification of properties was not presented. In this section, the influence of fabric properties on AFS system performance will be discussed.

An examination of the literature to determine documented evidence of the influence of fabric properties on performance does not reveal many sources where specific comparisons and/or quantification have been presented. Following is a general summary of the significant literature.

WES Study

The results of a full-scale traffic test conducted by the Waterways Experiment Station, Vicksburg, Mississippi, have been published (7). Two test sections, each containing a fabric and one test section without fabric were constructed. The subgrade was placed to have a CBR of about 1 in the upper 25 cm (10 inches) and a CBR ranging from 1.5 to 2.3 in the next 35 cm (14 inches). A crushed limestone layer, 35 cm (14 inches) thick was placed above this subgrade with the respective fabric in each of the two test sections. The two fabrics used were Bidim* C-38 spunbonded polyester and T-16 (a neoprene-coated, one ply, woven, nylon). The fabric properties were (7):

	"Bidim" C-38	T-16
Elongation @ Failure:	58%	31%
Breaking Strength:	49 kN/m (280 lb/in)	76 kN/m (435 lb/in)
Modulus: (calculated by authors)	67 kN/m (380 lb/in)	300 kN/m (1720 lb/in)

The performance of these three test sections subjected to traffic by a tandem axle, dual wheel, military dump truck is depicted in Figure 1.

The T-16 fabric had a much higher modulus than the C-38 and thus, the influence of the higher modulus fabric is evident. For 900 vehicle passes the T-16 fabric section had about 5 cm (2 inches) of rutting while the "Bidim" C-38 section had about 18 cm (7 inches) of rutting. The section without fabric sustained only 200 vehicle passes to 15 cm (6 inches) of rutting.

Kinney and Barenberg

Kinney and Barenberg (8) have published performance data from small-scale repeated load tests on AFS systems containing two fabrics designated M-1 and W-2. They reported a modulus for these fabrics of 53 kN/m (300 lb/in) and 193 kN/m (1100 lb/in), respectively (8) and concluded that the higher modulus fabric improved performance as a result of greater confinement in the aggregate and resultant greater "load spreading ability" of the aggregate. Barenberg (9) has developed a design method for these two fabrics. Using this method, it can be shown that an ~ 10% reduction in aggregate thickness can be made if the high modulus fabric is used in lieu of the low modulus one.

Giroud and Noiray

Giroud and Noiray (15) have developed a design method which requires fabric modulus and failure elongation as design inputs. For the design conditions of CBR=0.5, rut depth = 30 cm (12 inches) and N=1000, this design method allows a reduction in aggregate thickness ranging from 25 to 40 percent for fabric modulus values ranging from 10 to 200 kN/m (60 to 1200 lb/in) (see Figure 3). Again it is seen that high modulus fabrics reduce the required amount of aggregate thickness.

Georgia Tech Study

A major study concerning the use of geotextiles in AFS systems is being conducted in the School of Civil Engineering at the Georgia Institute of Technology, Atlanta, Georgia. A number of papers based on this study have already been placed in the technical literature (1,11,12,13,14).

In one phase of this study, a scale model test apparatus was used to evaluate relative performance characteristics of various AFS systems and to evaluate the relative significance of important parameters on the system performance. Details of the testing method have been reported elsewhere (13) but the following is a brief summary of the equipment and test method:

1. 0.9 m (3 ft) diameter test pit with 38 cm (15 inches) thick, soft silty clay subgrade and dense-graded aggregate with layer thicknesses ranging from 13 to 33 cm (5 to 13 inches).
2. Subgrade soil prepared and placed to have a vane

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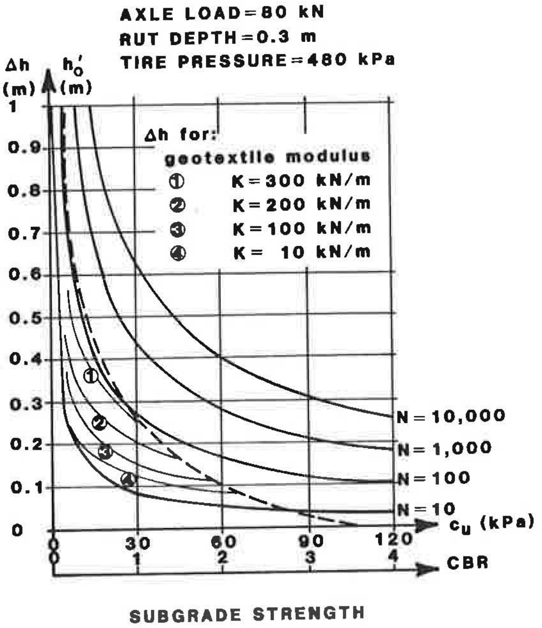

Fig. 3 Aggregate Thickness h_o' (Case without fabric) and Aggregate Thickness Reduction, Δh (Case with fabric) as a Function of Subgrade Strength (Redrawn from Ref. 15).

shear strength ≡ 28 kPa (4 psi) and CBR ≡ 0.9.

3. Fabric placed between soil and aggregate.
4. Repeated loading applied on 15 cm (6 inch) diameter plate with contact pressure = 480 kPa (70 psi), repetition rate = 20 per minute, and pulse duration = 0.2 sec.
5. During loading, vertical movement of loading plate is monitored.

In order to develop insight as to the manner in which a variety of fabric properties influence AFS system performance, two test series were conducted as part of the study. In one series of scale model pit tests, different types of commercially available nonwoven fabrics, e.g. Typar* spunbonded polypropylene fabric, Terram** construction membrane, Supac*** nonwoven polypropylene fabric, "Bidim", and 3 diagnostic membranes were tested under appoximately the same conditions (e.g., aggregate thickness, subgrade strength, and loading). In a second series, different basis weights of "Typar" were similarly tested. Table 1 summarizes pertinent characteristics of the fabrics and membranes and general test conditions for Test Series I. In all cases, the primary measure of performance was surface rutting of the AFS system. Table 2 summarizes the performance results from Test Series I.

The results were analyzed in a number of ways. In Figure 4, the general effect of initial fabric modulus on the initial rate of rut formation is shown. Figure 5 depicts the influence of initial fabric modulus on the number of repetitive loads required to cause either 5 or 10 cm (2 or 4 inches) of rutting in the AFS system. From these figures, it is obvious that increased fabric modulus relates quite significantly to increased rutting resistance.

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**Registered Trademark of ICI Fibers
***Registered Trademark of Phillips Fibers Corporation

Table 1. Fabric and Test Condition Summary--Test Series I.

Test	Fabric or Membrane	E_o (a) kN/m	Aggregate Thickness, cm	Subgrade Shear Strength, kN/m^2
I-1	"Typar" 3401	137	18.4	36
I-2	"Typar" 3251	100	18.5	30
I-3	"Terram" 1000	81	18.2	29
I-4	"Bidim" C-22	18	17.8	31
I-5	"Bidim" C-34	28	19.3	33
I-6	"Supac" 5P	30	18.7	33
I-7	Kevlar*(Aramid woven fabric)	1130	18.3	33
I-8	Dental Dam (sheet rubber)	0.5	17.3	31
I-9	Teflon*(sheet)	121	17.6	32
I-10	None	0	17.5	28

Footnotes:

(a) E_o = initial tangent fabric modulus (wide width tensile test).

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Table 2. Selected Performance Results from Test Series I AFS System Tests.

Test Designation	Number of Load Applications to Given Rut Depth					Initial Rate of Rut Formation(a), cm/cy
	2.5 cm	5 cm	7.5 cm	10 cm	12.5 cm	
I-1	37	72	120	220	385	0.068
I-2	26	51	76	116	170	0.096
I-3	22	38	55	82	130	0.114
I-4	9	14	26	48	90	0.278
I-5	27	50	62	88	140	0.093
I-6	47	66	77	95	126	0.053
I-7	57	205	630	8000	-	0.044
I-8	18	22	24	28	32	0.139
I-9	45	63	89	115	120	0.056
I-10	11	29	52	72	102	0.227

Footnote:

(a) Initial rate of rut formation = $\frac{2.5 \text{ cm}}{N @ 2.5 \text{ cm rut}}$

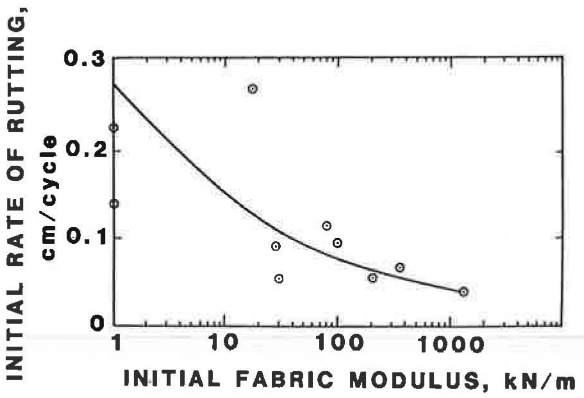

Fig. 4 Effect of Fabric Modulus on Initial Rate of Rutting (0.9 m Test Pit).

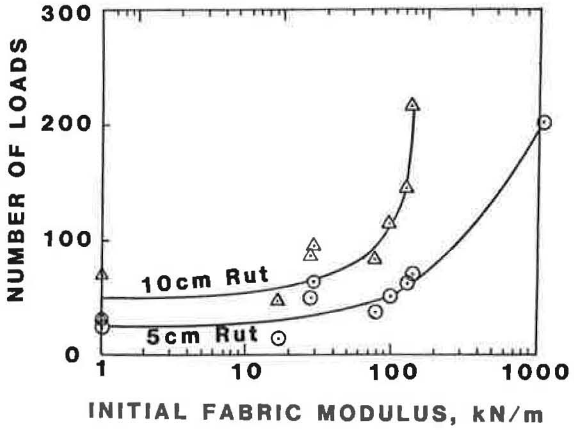

Fig. 5 Effect of Fabric Modulus on Number of Load Applications Required to Cause 5 and 10 cm Rut (0.9 m Test Pit).

The second test series was conducted wherein only various basis weight fabrics ranging from 70 to 270 g/m^2 (2 to 8 oz/yd^2) of "Typar" spunbonded polypropylene were included in the AFS systems. Figure 6 depicts the data relating initial modulus, E_0 and modulus at 10 percent elongation E_{10} to the number of load applications for 7.5 cm (3 inches) of rutting. Again the significant effect of fabric modulus on AFS performance and rutting resistance is quite obvious.

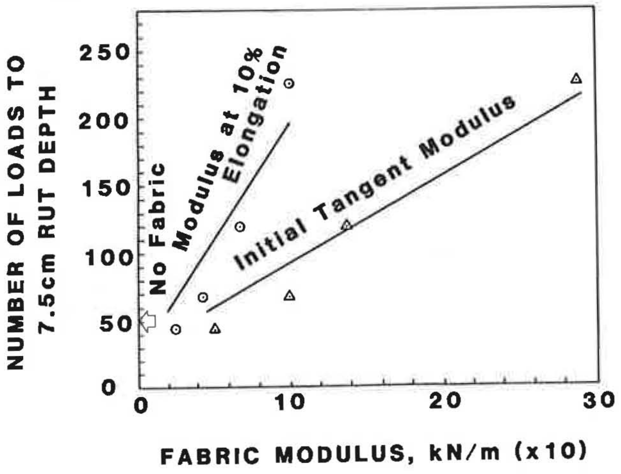

Fig. 6 Effect of Fabric Modulus of Number of Load Applications to Cause 7.5 cm Rut Depth (Basis Weight Series).

Other Studies

Kinney (22) has concluded, based on experimental and theoretical analyses, that the "ideal fabric from the standpoint of structural reinforcement will have a high ratio between tension and strain (i.e., high modulus) and a low tendency to creep to lower loads at constant strain" (i.e., low stress relaxation). However, exceedingly high tensile stress in the fabric can only be developed if adequate anchorage accompanies and for typical AFS systems, anchorage is limited by friction/adhesion, the amount of surcharge (aggregate thickness) and the length of embedded fabric outside the loaded area.

Raad (23), in his theoretical analysis of the effect of prestressing the fabric on behavior also indicates that high tension in the fabric is beneficial but that the in-plane stress is limited by frictional capabilities. He found that fabric prestressing reduced surface deflection and maximum shear stress in the subgrade.

EFFECT OF FABRIC PROPERTIES ON SYSTEM DESIGN

Based on the previous discussions, it is apparent that fabric modulus has an important effect on AFS system performance and as such should be considered in design. The authors are aware of 8 design methods generally available at this time (5,10,15,16,17,18,19,20). Of these eight, six are fabric-specific.

The more general non-fabric-specific design method developed by Giroud and Noiray (15) considers directly the effect of fabric modulus and failure elongation on design of AFS systems. A typical thickness design chart for this method is shown in Figure 3. Using this method, Figure 7 was developed and shows the general influence of fabric modulus on aggregate thickness requirements.

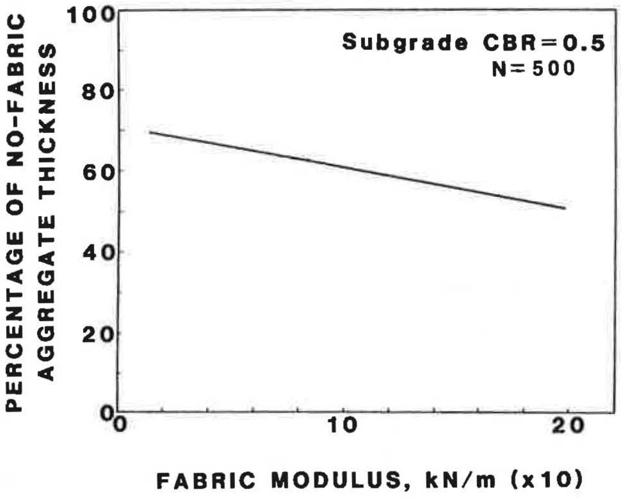

Fig. 7 Effect of Fabric Modulus on Design Thickness of Aggregate (From Ref. 15).

The method by the United States Forest Service (5) does not take into consideration any fabric properties except to indicate that "Preliminary information from trial use projects show that the lightweight nonwoven fabrics [135 g/m^2 (4 oz/yd^2)] performed as well as the heavier [270 to 540 g/m^2 (8 to 16 oz/yd^2)] once they were installed". The USFS method does suggest that a grab strength of $\geq$ 530 N (120 lbs) and an elongation $\geq$ 50% at failure are fabric requirements.

Using the fabric-specific design methods, it is virtually impossible to determine quantitative effects of fabric properties on thickness design due to differences in basic design assumptions (performance, number of loads, etc.).

DISCUSSION

Numerous mechanical properties of the fabric are important to the performance and design of AFS systems. The previous discussion has shown the tremendous importance of fabric modulus. Many other mechanical properties may be important, but their specific contribution, if any, has not yet been quantified. Maintenance of high levels of in-plane fabric stress are important to the performance of AFS systems and, thus, any fabric liabilities such as rupture, stress relaxation, or slippage are undesirable.

SUMMARY AND CONCLUSIONS

The effects of fabric properties on performance and design of aggregate-fabric-soil (AFS) systems have been discussed and quantified where possible. Primary emphasis has been placed on examining the effect of mechanical properties on performance and design. Data obtained from the pertinent literature and a study conducted at Georgia Tech were used. In general, it was found that the fabric modulus was the single most important fabric property governing the behavior of the AFS system.

Specific conclusions apparent from this paper are:

1. The use of a geotextile in an aggregate soil system can lead to improved system performance (e.g. longer service, reduced rutting) or alternately, a 25-40 percent reduction in the amount of required aggregate.
2. Quantitatively, the amount of performance improvement (aggregate reduction) resulting from the use of a particular fabric appears to correlate well with the modulus (resistance to stretch) of the fabric used. High modulus fabrics result in less rutting or better system performance than those with lower modulus.
3. Conceptually, it seems certain that other mechanical properties of the fabric are important for overall long-term system performance, although their specific effects have not yet been quantified. In general, a fabric with a good overall balance of properties is probably desired.

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