Base Course Contamination Limits

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Geotextiles have been used in pavement structures for two primary purposes: subgrade reinforcement and separation. Research to date has been concentrated on developing design procedures for incorporating geotextiles for subgrade reinforcement in areas with low-strength soils [California bearing ratio (CBR) < 3]. In this paper the use of geotextiles as a separation mechanism in roadways with higher strength soils (CBR > 3) is evaluated. The primary effect of geotextiles in this application is to reduce the amount of contamination within the aggregate base layer. Contamination of this layer occurs primarily through intrusion of subgrade materials into the aggregate base. This intrusion changes the gradation of the base and results in reduced strength or stiffness as well as lower permeability. Geotextiles reduce the contamination in the aggregate base by modifying the process of subgrade intrusion, the level of stress at the subgrade interface, and the process of filtration. A laboratory study was conducted to illustrate the influence of added fines on the modulus of an aggregate base. The aggregate tested was a 1-in.-minus crushed aggregate with 5.5 percent passing the No. 200 (0.075-mm) sieve. The study showed that, for the materials tested, up to 6 percent added fines can be tolerated without adversely affecting the stiffness of the base. For U.S. Forest Service base courses, separation geotextiles need to limit subgrade intrusion to this level. In situations in which drainage controls, the geotextile needs to limit intrusion to 2.5 percent. Primary benefits from geotextiles include increased life of the pavement structure or reduced initial and long-term capital outlays, or both.

Geotextiles have been used in pavement structures for two primary purposes: subgrade reinforcement and separation. Subgrade reinforcement involves the use of geotextiles in weak soil areas to reduce the amount of aggregate base required *(1)*. Separation involves using geotextiles to reduce or prevent intrusion of subgrade materials into aggregate base courses *(1–3)*. Research to date has been concentrated on developing design procedures for incorporating geotextiles for subgrade reinforcement. The effects of geotextiles as a separation layer in pavement structures have, at present, not been evaluated to any large degree and the design criteria and recommendations for their use have been based primarily on engineering judgment *(1, 2, 4–7)*. Because the number of weak soil areas is limited, it is expected that, in the future, the greatest potential use of geotextiles and the greatest source of cost savings will be their use as a separation layer in permanent roads.

The purpose of this paper is to illustrate the effect of geotextiles on the amount of contamination of aggregate bases under repeated loadings. "Contamination" of aggregate base courses may be more properly described as the intrusion of subgrade materials into aggregate bases. The primary effect of subgrade intrusion is to change the gradation of the aggregate base. It is through this change in gradation that the strength of the aggregate base and its permeability are affected.

Geotextiles reduce the contamination of aggregate bases by changing the process of subgrade intrusion. They modify the filtration process and may change the level of stress at the subgrade-aggregate interface. The filtration process is influenced by pore water pressures at the subgrade–aggregate base interface. It is thought that one of the influences of geotextiles is to change the manner in which pore water pressures develop, although the exact nature of this change is not fully understood *(8)*.

The amount of contamination may be expressed in two ways: percent increase in the fines content of the aggregate base (S) or by the soil contamination value (SCV). Percentage of added fines (S) represents the increase in weight of the aggregate base as a result of the contamination process, expressed in terms of the original dry weight of the aggregate base. SCV is the "weight of subgrade soil . . . passing the fabric per unit area of fabric," expressed in units of g/m^2 *(4)*. When geotextiles are used as a separation layer, the amount of contamination is reduced *(4, 5)* and the amount of contamination appears to depend on porosity, percentage open area, effective opening size, and thickness of the geotextile.

LABORATORY STUDY OF SUBGRADE INTRUSION

A laboratory study was conducted to evaluate the effect of added subgrade fines on the resilient modulus of an aggregate base. The primary purpose of this study was to quantify the variation in resilient modulus with varying amounts of subgrade fines. By illustrating the effect of subgrade intrusion on resilient modulus, the benefits of using geotextiles to limit intrusion can be demonstrated. An additional benefit of this study is that the information developed can be used to better account for the effects of subgrade intrusion in pavement design.

Factors That Affect Resilient Modulus of Granular Materials

The resilient modulus of granular materials has been found to depend on a number of factors. Seed et al. *(9)* reported seven factors that influence resilient modulus. Of these, the three most significant are type of aggregate, aggregate gradation, and confining pressure (or bulk stress). Bulk stress has been used by several authors *(9–11)* to characterize the resilient modulus of granular materials. Kalcheff and Hicks *(10)* developed a general test procedure for evaluating resilient modulus in the laboratory using a triaxial testing system and expressed the results in terms of bulk stress. In 1982 AASHTO published a

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TABLE 1 INDEX PROPERTIES OF AGGREGATE BASE

Test	Property
Specific gravity	
Coarse fraction (AASHTO T–85)	
Surface saturated dry	2.71
Bulk dry	2.68
Apparent	2.77
Absorption (%)	1.18
Fine fraction (AASHTO T–100)	2.74
Maximum density [Humphres' method *(13)*]	
Grading D	141.8 pcf
Grading E	139.2 pcf

TABLE 2 GRADATIONS OF AGGREGATE

U.S. Standard Sieve	Grading D (percentage passing)	Grading E (percentage passing)
1 in. (25.0 mm)	100.0	
3/4 in. (19.0 mm)	84.0	100.0
1/2 in. (12.5 mm)	74.0	84.0
3/8 in. (9.38 mm)	64.5	75.0
No. 4 (4.75 mm)	48.0	57.0
No. 8 (2.36 mm)	36.0	42.0
No. 30 (0.600 mm)	21.5	24.5
No. 100 (0.150 mm)	8.5	10.5
No. 200 (0.075 mm)	5.5	5.5

test procedure for determining the resilient modulus of subgrade soils (T–274) *(12)*. This procedure includes methods for both granular and cohesive soils. The laboratory study for this paper used bulk stress to characterize resilient modulus, and the test procedure used generally follows that presented by AASHTO.

Selection of Materials

The aggregate base tested was a crushed aggregate produced from an intrusive igneous rock. The engineering properties of this aggregate are given in Table 1. The aggregate was sampled from an existing stockpile and was blended in the laboratory to the gradations given in Table 2.

The gradations selected are typical of those specified for aggregate base courses used with bituminous concrete pavements. The gradations represent the middle of the specification range allowed in the 1979 U.S. Forest Service Standard Specifications *(14)*. A second consideration is that the maximum particle size of each gradation should be consistent with the size of the testing apparatus used in the laboratory study. Because 4-in. (10-cm) molds were used in this study, the maximum particle size could not be larger than 1 in. (25 cm).

The subgrade material selected for use as the added fines material was a low-plasticity clay with engineering properties given in Table 3.

Test Procedures

The approach used in this study consisted of

1. Blending the aggregate to the specified gradation;
2. Determining the maximum density of the crushed aggregate using Humphres' method of granular compaction *(13)*;
3. Performing resilient modulus tests on the crushed aggregate mixture compacted to approximately 95 percent maximum density;
4. Blending mixtures of aggregate and subgrade fines using 2, 4, 6, 8, and 19.5 percent of added fines; and
5. Performing resilient modulus tests on the aggregate–subgrade fines mixtures compacted to approximately 95 percent maximum density.

All tests were performed using a triaxial cell 4 in. (10 cm) in diameter with an MTS testing machine used to apply the appropriate vertical loads. The MTS machine was set to apply a load duration of 0.1 sec, with a cycle length of 2 sec. The stress pulse was programmed to approximate a rectangular form. An initial seating pressure of 1 psi (6.9 kPa) was used for all specimens.

Test Conditions

A program was established to conduct resilient modulus testing over the range of stresses encountered in typical pavement structures used on National Forest roads. The method of analysis used to determine this range of stresses was the Boussinesq method of equivalent thickness *(15)*. Figure 1 shows the typical bituminous concrete pavement evaluated. In a linear elastic system, the computed stresses depend on the assumed relation-

TABLE 3 ENGINEERING PROPERTIES OF THE ADDED FINES

Property	Measured
Gradation	
U.S. standard sieve (% passing)	
No. 10 (2.00 mm)	99.5
No. 40 (0.425 mm)	97.8
No. 200 (0.075 mm)	90.2
(0.020 mm)	83.6
(0.002 mm)	54.9
(0.001 mm)	43.4
Atterberg Limits	
Liquid limit (AASHTO T–89), %	45.3
Plastic limit (AASHTO T–90), %	22.9
Plasticity index (AASHTO T–90), %	22.4
Soil Classification	
Unified (ASTM D2487)	CL
AASHTO (AASHTO M–145 and ASTM D3282)	A–7–6
Moisture-Density Relationship	
Maximum density (AASHTO T–99), pcf	106.2
Optimum moisture (AASHTO T–99), %	19.1
Specific gravity (AASHTO T–100)	2.75

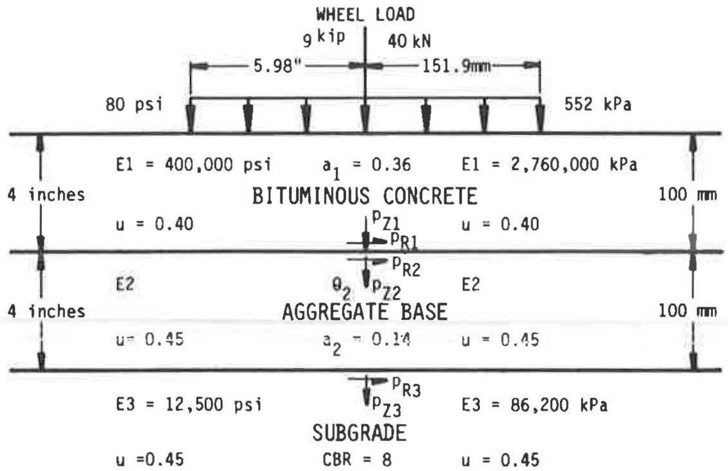

FIGURE 1 Typical pavement section.

TABLE 4 SUMMARY OF GEOTEXTILES TESTED FOR SUBGRADE INTRUSION BY WALTER *(18)*, HOARE *(4)*, AND BELL ET AL. *(5)*[1]

Geoxtexile	Researcher	S (%)	SCV (g/m^2)	EOS[2]	T[3]
MIRAFI 500X	Walter	0.00	0	0.053	0.62
TYPAR 6	Walter	0.00	0	0.175	0.48
TYPAR 6	Walter	0.09	90	0.175	0.48
TYPAR 6	Walter	0.62	600	0.175	0.48
W3	A.L. Bell	-	708	0.080	0.40
W8	A.L. Bell	-	737	0.100	na
NW4	A.L. Bell	-	777	0.170	2.00
NW5	A.L. Bell	-	839	0.170	4.00
NW3	A.L. Bell	-	849	0.130	3.50
SUPAC 4-P	Walter	0.95	910	na	1.27
BIDIM C42	Walter	1.02	980	0.175	4.03
Terram 1000	Hoare	-	1050	0.140	na
W4	A.L. Bell	-	1139	0.060	0.30
W7	A.L. Bell	-	1179	0.190	na
Neomer T425	Hoare	-	1240	0.100	na
NW1	A.L. Bell	-	1290	0.130	2.00
FIBRETEX 200	Walter	1.43	1370	0.175	2.89
Neomer PB127	Hoare	-	1400	0.110	na
W5	A.L. Bell	-	1403	0.200	0.35
FIBRETEX 200	Walter	1.51	1450	0.175	2.89
NW2	A.L. Bell	-	1605	0.130	3.00
W1	A.L. Bell	-	1922	0.300	0.03
FIBRETEX 200	Walter	2.02	1940	0.175	2.89
W6	A.L. Bell	-	2027	0.140	0.32
BIDIM C42	Walter	2.57	2470	0.175	4.03
MIRAFI 140	Walter	3.30	3170	0.150	0.77
W2	A.L. Bell	-	3766	0.430	0.60
FIBRETEX 200	Walter	3.99	3840	0.175	2.89
MIRAFI 140	Walter	3.99	3840	0.150	0.77
MIRAFI 140	Walter	5.61	5390	0.150	0.77
BIDIM C34	Walter	5.94	5720	0.175	2.82
MIRAFI 140	Walter	6.05	5820	0.150	0.77
Filter X	Walter	6.25	6010	na	na
MIRAFI 140	Walter	7.88	7570	0.150	0.77

Notes:

1. The test values above are listed in rank order of % Intruded Fines (S), and Soil Contamination Value (SCV).
2. EOS is the Equivalent Opening Size of the geotextile in mm. (Some researchers use O_{95}).
3. T is the thickness of the geotextile in mm.

The number of load repetitions applied are as follows: Walter (18) - 100,000; Hoare (4) - 27,000; A.L. Bell (5) - Not reported.
na = not available.

ship between the modulus of the aggregate base course (E2) and the modulus of the subgrade (E3). This ratio has been found to range between 2 and 3 for most situations *(15, 16)*. For the pavements sections analyzed in Figure 1, the following stresses were calculated, and they represent the maximum bulk stress in the aggregate base immediately below the bituminous layer:

E2/E3	*Horizontal Stress (psi)*	*Vertical Stress (psi)*	*Bulk Stress (psi)*
2	1.8	30.0	33.5
3	3.0	35.0	41.0

The percentages of added fines selected for testing were 2, 4, 6, 8, and 19.5 percent. The values 2, 4, 6, and 8 percent represent the range of added fines noted by other researchers *(4, 5, 18)* for situations in which geotextile separators are used. The 19.5 percent value represents the condition determined by Walter *(18)* when geotextiles are not used. Table 4 gives a summary of the geotextiles tested by Hoare *(4)*, Bell et al. *(5)*, and Walter *(18)* in rank order of percentage of intruded fines. It should be noted that the reported values are subject to product and soil variations.

Resilient Modulus Tests

All modulus tests were conducted over a range of confining pressures and vertical stresses. In addition, the order in which confining pressures and vertical stresses were applied to the test specimens was varied for some of the tests. Two criteria were considered in selecting the range of vertical stresses applied. The first was to select vertical stresses that would simulate the stress condition within the pavement section shown in Figure 1. The second was to select vertical stresses over a range so as to produce a ratio between deviator stress and confining pressure of between 1 and 5. Vertical stresses were applied, during testing, in 5-psi (34.5-kPa) increments.

Table 5 gives a summary of the stress conditions for each test series. The numbering system identifies each series of tests according to the incremental increase in added fines rather than the sequential order in which testing was conducted. The test series used to develop the relationship between bulk stress (θ) and resilient modulus (E2) are indicated. Grading D was selected for the tests to develop this relationship. Grading D was selected over Grading E because of its greater use on Forest Service roads.

As noted, the order of applying confining pressures was varied during the initial stages of testing. Test Series 1–4 were essentially trial tests. The most consistent results occurred when the testing was initiated with a confining pressure of 15 psi (103.5 kPa). Test Series 8 was a retest of Series 7 using the preferred order of applying confining pressures. This procedure is similar to that described in AASHTO T–274 for granular soils.

Reduction of Test Data

The relationship between state of stress and resilient modulus has been characterized for this study using bulk stress. Bulk stress (θ) is defined as the sum of the three principal stresses:

$$\theta = p_1 + p_2 + p_3 \tag{1}$$

where

p_1 = major principal stress or total vertical stress,

TABLE 5 SUMMARY OF RESILIENT MODULUS TESTING PROGRAM

Test Series	Aggregate Grading	Added Fines %	Moisture Content,%	Compaction Level,%	Order of Applying Confining Pressure, psi
1	E	0	4.14	95.0	2, 5, 10, 15, 20
2	E	0	7.13	95.0	20, 15, 10, 5
3	D	0	4.79	94.5	5, 10, 15, 20
4	E	0	4.92	95.6	20, 15, 10, 5, 2
5*	D	0	5.46	95.6	20, 5, 10, 15
6*	D	2	5.69	95.0	5, 10, 15, 20
7	D	4	5.93	95.0	20, 15, 10, 5, 2
8*	D	4	5.93	95.0	15, 10, 5, 2, 20
9*	D	6	6.27	95.8	15, 10, 5, 2, 20
10*	D	8	6.61	96.0	15, 10, 5, 2, 20
11*	D	19.5	7.50	96.5	15, 10, 5, 2, 20

*Test series used to develop the relationship between resilient modulus (E2) and bulk stress (θ).

TABLE 6 LINEAR REGRESSION ANALYSIS OF DATA: $E2 = K*\theta^n$ (psi)

Percentage of Added Fines	K	n	r^2
0	8620	0.422	0.886
2	4730	0.557	0.793
4	4210	0.625	0.698
6	4250	0.662	0.896
8	1770	0.688	0.725
19.5	9320	0.256	0.906

Note: The values of E2 have been rounded to the nearest 100 psi.

p_2 = minor principal stress, and
p_3 = minor principal stress.

For the triaxial testing system used, $p_2 = p_3$. Both of these stresses equal the confining pressure.

The test data were analyzed with linear regression techniques using the equation: $E2 = K*\theta^n$. E2 is the resilient modulus of the aggregate base, K and n are constants determined in the regression analysis, and θ is the bulk stress. The relationship between E2 and θ was developed using the data corresponding to confining pressures of 5, 10, and 15 psi (34.5, 69, and 103.5 kPa). For S-values of 4, 6, and 8 percent, some E2-values determined at a confining pressure of 5 psi (34.5 kPa) were not used in the regression analysis because some of these data did not produce reasonable results. For the situation with 19.5 percent added fines, the aggregate subgrade mixture acted more like a soil than an aggregate. This was because a total of 24 percent of the material in the specimen passed the No. 200 (0.075-mm) sieve. For this series of tests, the relationship between E2 and θ was developed using confining pressures of 2, 5, and 10 psi (13.8, 34.5, and 69 kPa). These stresses are consistent with those used to test most subgrade soils. Tables 6 and 7 give summaries of the values for K, n, θ, and E2 as a function of the percentage of added fines. Figures 2–7 show the relationship between θ and E2 for each value of percentage of added fines.

TABLE 7 RESILIENT MODULUS (E2)

Percentage of Added Fines	Bulk Stress (psi) 10	20	30	35	40	95	100
0	22,800	30,500	36,200	38,700	40,900	59,000	60,300
2	17,100	25,100	31,500	34,300	36,900	59,900	61,600
4	17,700	27,300	35,200	38,800	42,100	72,500	74,700
6	19,500	30,900	40,400	44,800	48,900	86,900	89,800
8	8,600	13,900	18,400	20,400	22,400	40,700	42,100
19.5	16,800	20,000	22,200	23,100	23,900	29,900	30,300

Note: The values of E2 have been rounded to the nearest 100 psi.

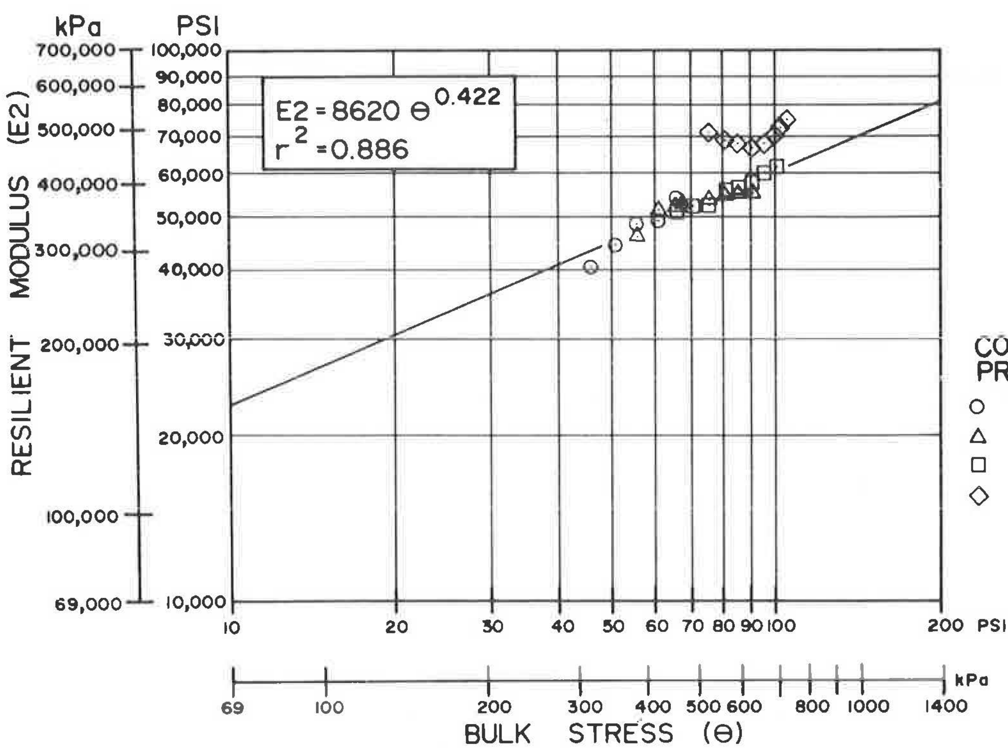

FIGURE 2 Resilient modulus versus bulk stress: Grading D (original gradation).

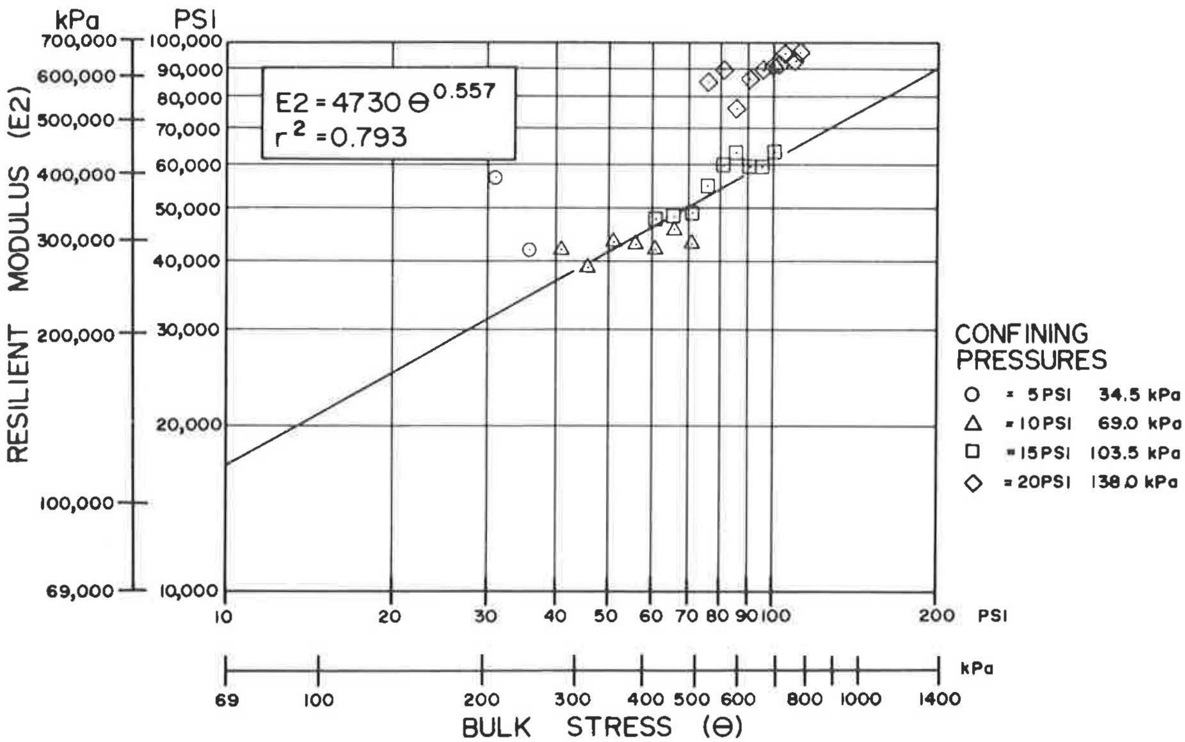

FIGURE 3 Resilient modulus versus bulk stress: Grading D with 2 percent added fines.

Relationship Between Resilient Modulus and Added Fines

The relationship between resilient modulus of the aggregate base (E2) and percentage of added fines (S) is shown in Figures 8 and 9. In Figure 8 resilient modulus has been plotted as a function of bulk stress (θ) for the various percentages of added fines (S). In Figure 9 resilient modulus is shown as a function of percentage of added fines (S) for four levels of bulk stress: θ = 10, 20, 35, and 95 psi (θ = 69, 138, 241, and 655 kPa). This encompasses the range of conditions used in the laboratory tests. A bulk stress of 35 psi represents the stress state in the

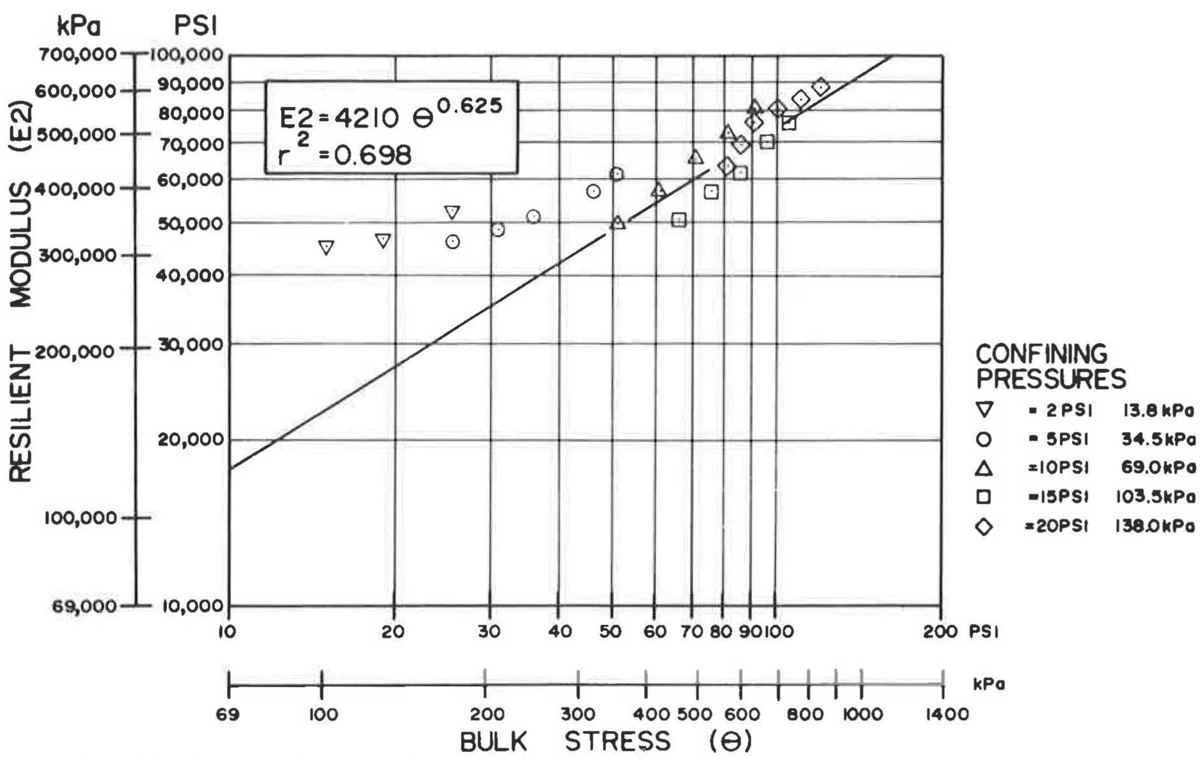

FIGURE 4 Resilient modulus versus bulk stress: Grading D with 4 percent added fines.

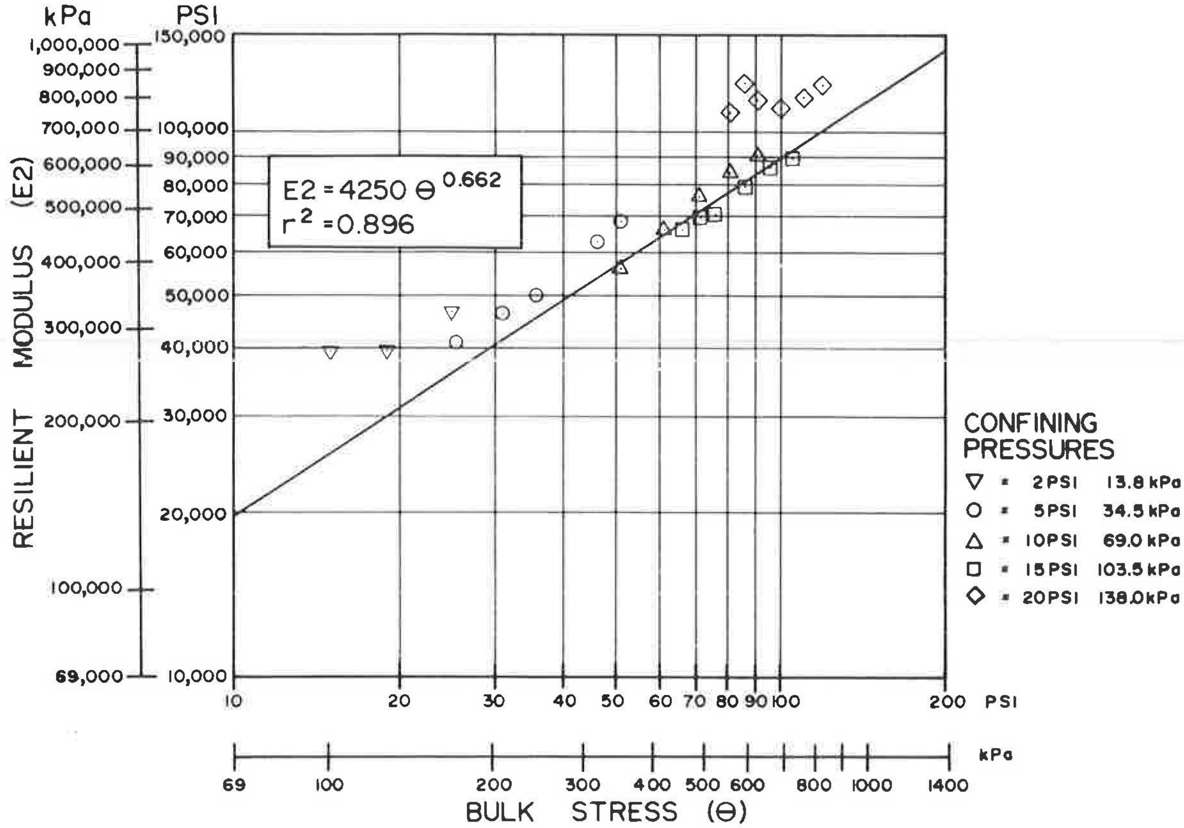

FIGURE 5 Resilient modulus versus bulk stress: Grading D with 6 percent added fines.

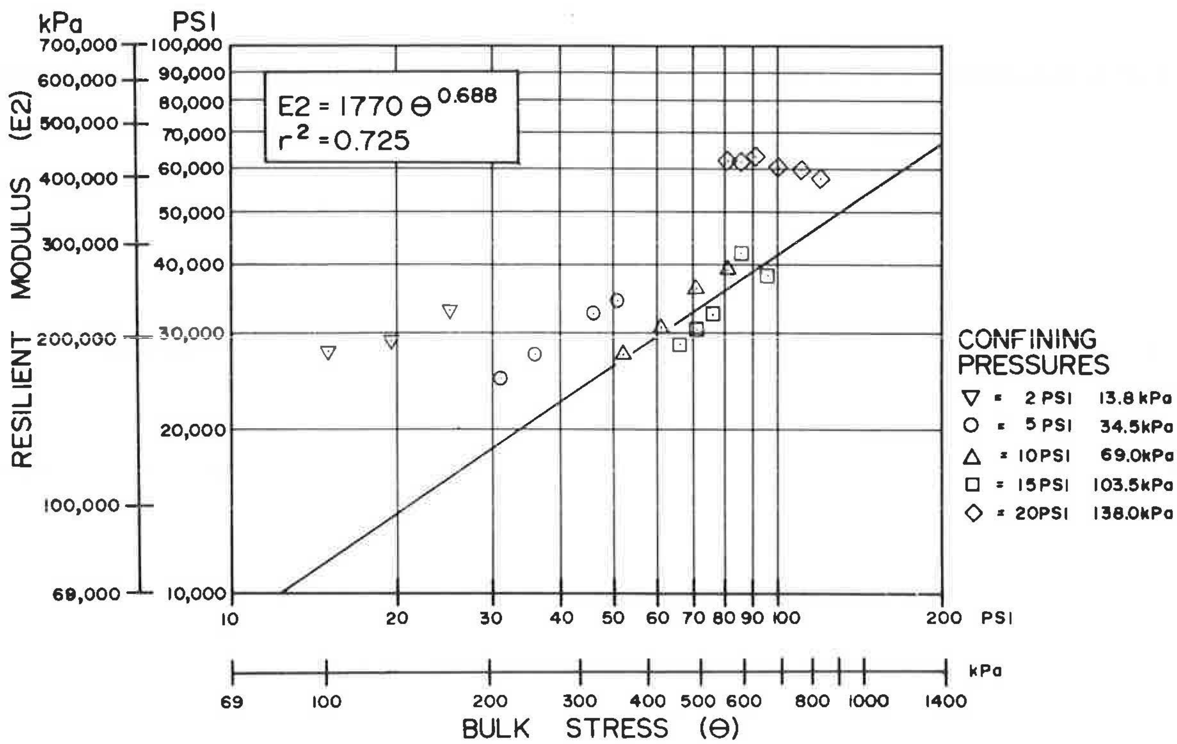

FIGURE 6 Resilient modulus versus bulk stress: Grading D with 8 percent added fines.

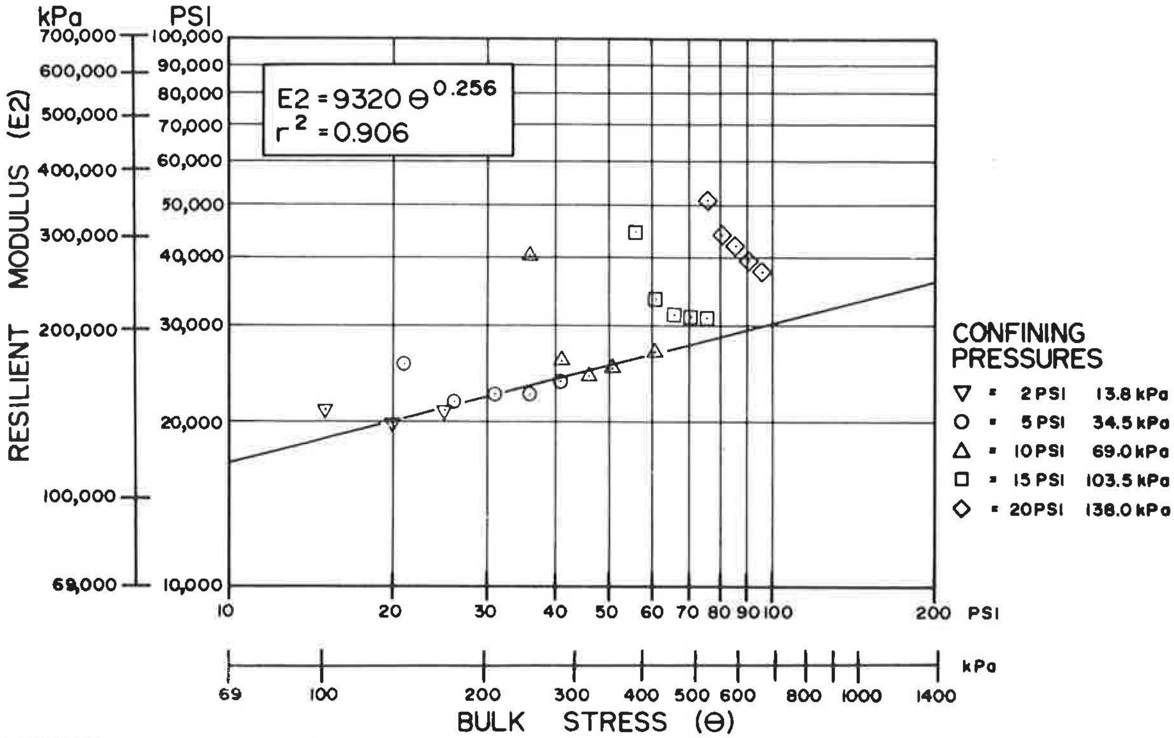

FIGURE 7 Resilient modulus versus bulk stress: Grading D with 19.5 percent added fines.

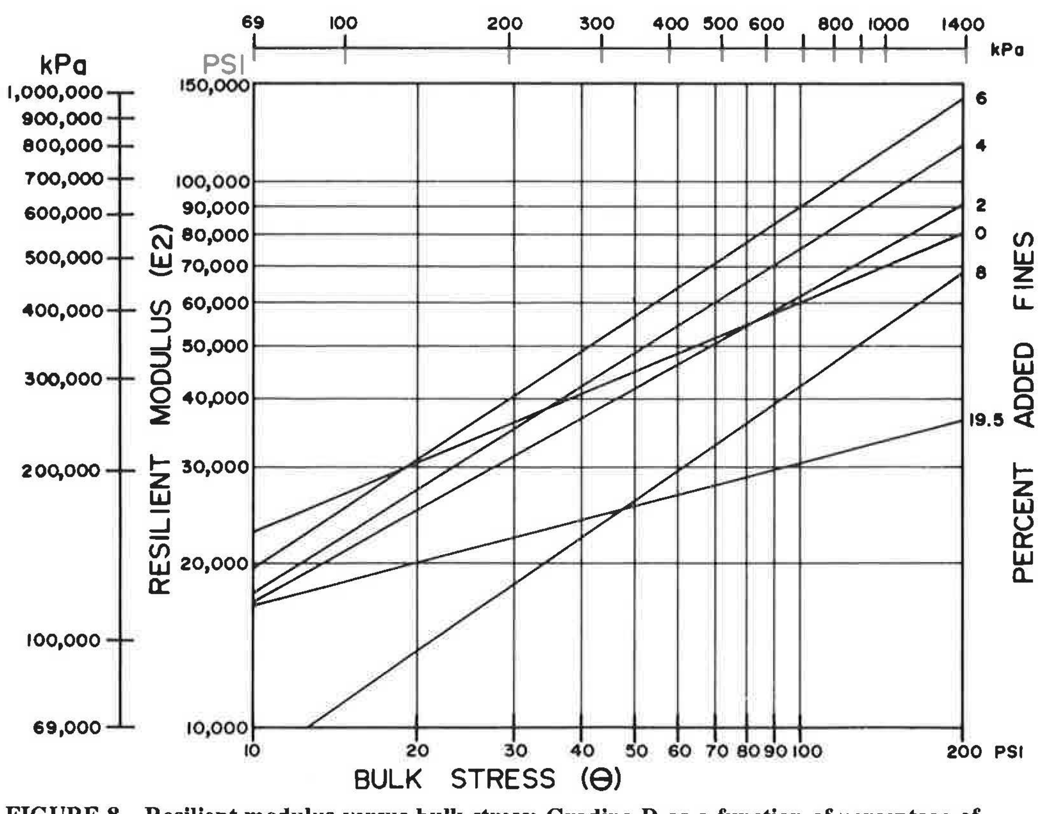

FIGURE 8 Resilient modulus versus bulk stress: Grading D as a function of percentage of added fines.

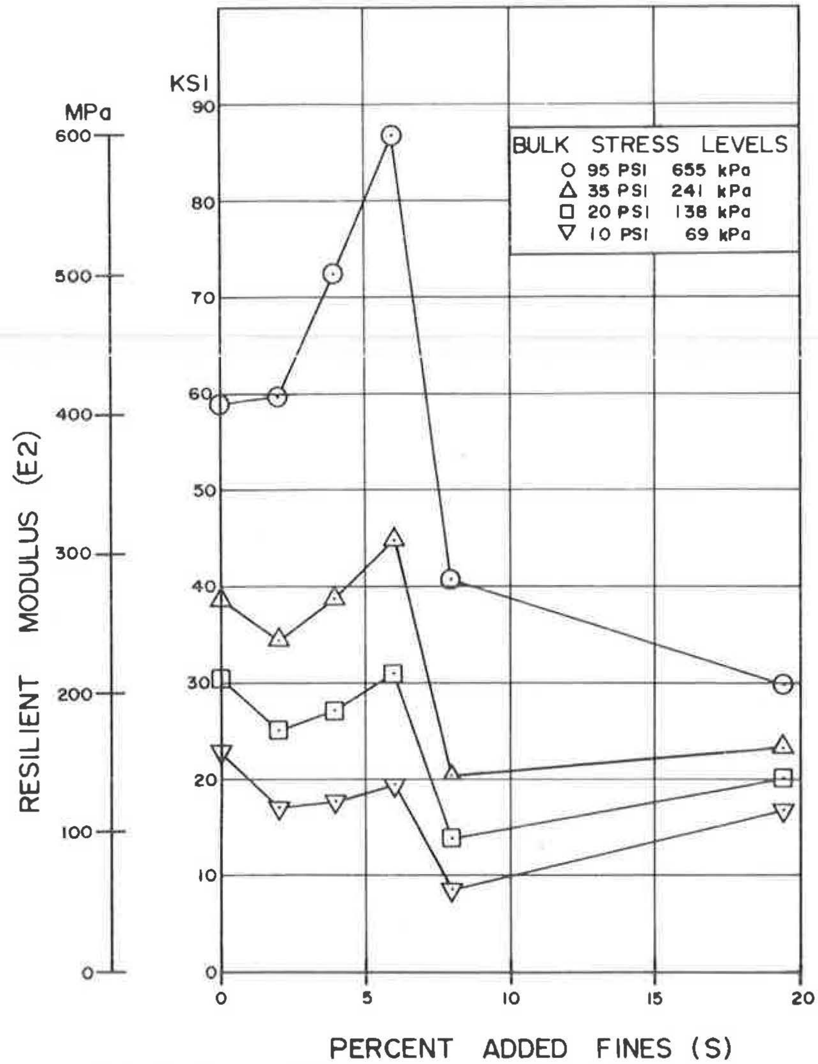

FIGURE 9 Resilient modulus versus percentage of added fines.

aggregate base course, and a bulk stress of 20 psi is representative of the stress state in the subgrade.

If the variable F is defined to represent the percentage of material passing the No. 200 (0.075-mm) sieve, then the term F includes the fines in the original aggregate base (F_0), as well as the added subgrade fines (S), or $F = F_0 + S$. For the situation tested, F_0 is 5.5 percent; E2 reaches its peak when S is 6 percent or when F is 11.5 percent. One reason for setting an upper limit for F_0 is to permit drainage within the aggregate base. For a project situation, in which the aggregate base produced has about 8 percent passing the No. 200 (0.075-mm) sieve, an additional 3.5 percent added fines can be tolerated over the life of the pavement structure before a loss in pavement strength occurs. However, under this condition, the drainage characteristics of the base material could be impaired. For a "down the middle of the spec" situation (which is the condition tested), 2.5 percent added fines should probably be considered the apparent upper limit of F (percent passing No. 200) for drainage purposes, whereas 6 percent added fines could be tolerated from a stiffness standpoint.

At a bulk stress of 95 psi (655 kPa), the test data show an increase in resilient modulus of the aggregate base (E2) as the percentage of added fines (S) increases. An apparent peak in E2 was reached when the percentage of added fines reached 6 percent. At 8 percent added fines, a dramatic drop in E2 was experienced. Coincidentally, the increase in E2 occurred over a range in S, which appears to correspond to a range of values allowed in the crushing specifications *(14)*. Grading D specifies 8 percent as a maximum allowed to pass the No. 200 (0.075-mm) sieve.

For bulk stress levels of 20 and 35 psi (138 and 242 kPa), an initial decrease in E2 was noted as S went from 0 to 2 percent. As S increased from 2 to 6 percent, an increase of E2 was experienced, and it reached an apparent peak at 6 percent. As with a bulk stress of 95 psi (655 kPa), a dramatic drop in E2 occurred when 8 percent added fines were used. It is interesting to note that E2 experienced a slight increase when S was increased to 19.5 percent. However, E2 at 19.5 percent was still significantly below the initial value of E2. In summary, it appears that up to 6 percent added fines can be tolerated in terms of stiffness criteria for aggregate bases for all the stress levels evaluated.

EVALUATION OF TEST RESULTS

Effect of Added Fines on Pavement Life

The influence of added fines on the life of a pavement structure was evaluated for added fines values of 0, 2, 4, 6, 8, 10, and 12 percent. These values represent the range of intrusion experienced in a field study of National Forest roads *(19)*, as well as those reported in several laboratory studies *(4, 5, 18)*. Also evaluated is the situation in which the aggregate base is contaminated to the point where it acts as a subgrade. This is represented by S = 19.5 percent. The three analysis procedures used were

1. U.S. Forest Service: AASHTO equation *(20)*,
2. Boussinesq method of equivalent thickness: BOUSS *(15)*, and
3. Elastic layered theory: ELSYM5 *(10)*.

In the U.S. Forest Service method, the structural strength of the aggregate base is characterized by the a-value. Resilient modulus is used to characterize the layer contribution of the aggregate base in the BOUSS and ELSYM5 analysis procedures. The structural contribution of the geotextile was ignored in all analysis methods. Only its role in preventing contamination in the base layer was considered.

Each method of characterizing the contribution of the base shows that a relative reduction in structural strength is experienced as the percentage of added fines (S) increases. To document this change, a structural equivalency ratio (SER) has been defined as the ratio of the structural contribution of a contaminated base to that of a new aggregate base as follows:

$$\text{E2 SER} = (\text{E2 for any S})/(\text{E2 for S} = 0) \quad (2)$$

$$\text{a-value SER} = (a_2 \text{ for any S})/(a_2 \text{ for S} = 0) \quad (3)$$

A bulk stress of 35 psi (241 kPa) was selected to determine the structural equivalency ratios for this paper. Table 8 gives the values of E2 calculated for each level of percentage of added fines (S) using the equations in Tables 6 and 7 as well as the associated SERs. The ratios range from 1.158 at 6 percent added fines to 0.527 at 8 percent. Structural equivalency ratios greater than 1.0 reflect the increase in resilient modulus experienced in the laboratory as S was increased from 0 to 6 percent. In subsequent analyses, the SERs for S = 0, 4, and 6 percent are set equal to 1.0. The ratio at S = 2 percent was kept as 0.886 to illustrate the effect on pavement life of a slight change in E2-values.

For a bulk stress level of 35 psi (241 kPa), SER for S = 19.5 percent was larger than for S = 8 percent. Because it is reasoned that at 19.5 percent added fines the aggregate base is acting much like a subgrade material, the ratio E2/E3 was set equal to 1.0 for all subsequent analysis. This resulted in an SER of 0.333. The SER-values for 10 and 12 percent added fines were determined using a linear interprolation after making the assumption that E2 gradually decreases between 8 and 19.5 percent added fines. The pavement section analyzed therefore had an E2-value of 37,500 psi (258 600 kPa) for the original aggregate base and a subgrade resilient modulus (E3) of 12,500 psi (86 200 kPa).

In the AASHTO design equation, the effect of added fines on the layer equivalency of an aggregate base is accounted for by varying the a-value of the aggregate base layer (a_2). The U.S. Forest Service method *(20)* incorporates a method for estimating a_2-values for aggregate base and for other materials used in layered systems. The factors that influence the a_2-values include

TABLE 8 DEVELOPMENT OF STRUCTURAL EQUIVALENCY RATIOS BASED ON RESILIENT MODULUS

S, %	E2 psi	Calculated E2 SER	Calculated E2/E3	Design E2 SER	Design E2/E3	Design E2 psi
0	38,700	1.000	3.00	1.000	3.00	37,500
2	34,300	0.886	2.66	0.886	2.66	33,225
4	38,800	1.003	3.01	1.000	3.00	37,500
6	44,800	1.158	3.47	1.000	3.00	37,500
8	20,400	0.527	1.58	0.527	1.58	19,750
10	---	---	---	0.493	1.48	18,500
12	---	---	---	0.460	1.38	17,250
19.5	23,100	0.597	1.79	0.333	1.00	12,500

Notes:
E2 = 3*E3 at S = 0 percent.

E2 at S = 19.5% set so that E2 = E3.

Design SER for S = 10 and S = 12% are based on linear interpolation.

TABLE 9 DETERMINATION OF a-VALUES AND CORRESPONDING STRUCTURAL EQUIVALENCY RATIOS BASED ON U.S. FOREST SERVICE a_2-VALUE CRITERIA *(24)*

Criteria	S (%) 0	2	4	6	8	10
Fractured aggregate	0.08	0.08	0.08	0.08	0.08	0.08
Plasticity, PI less than 6	0.01	0.01	0.01	0.00	0.00	0.00
Quality	0.02	0.02	0.02	0.02	0.01	0.00
P 200: 0–8	0.01	0.01	0.00	0.00	0.00	0.00
P 4: 30–65	0.01	0.01	0.01	0.01	0.01	0.01
P 1½ in: 100	0.01	0.01	0.01	0.01	0.01	0.01
Composite a-value	0.14	0.14	0.13	0.12	0.11	0.10
a-value SER	1.000	1.000	0.928	0.857	0.786	0.714

Note: Subgrade CBR = 8, which is equivalent to a = 0.07; a-value at S = 19.5 percent is set equal to the a-value of the subgrade.

1. Type of aggregate,
2. Plasticity,
3. Aggregate quality, and
4. Gradation.

Three types of aggregate are considered: cinders, sand and gravel, and fractured rock. Plasticity incorporates both plasticity index (AASHTO T–90) and sand equivalent (AASHTO T–176). Aggregate quality is a subjective determination, with three possible levels: marginal, good, and excellent. Gradation criteria include limitations on No. 200 (0.075-mm), No. 4 (4.75-mm), and 1½-in. (37.5-mm) sieves.

This method was used to determine a-values for the aggregate base over the range of percentage of added fines under consideration: 0, 2, 4, 6, 8, and 10 percent. For 10, 12, and 19.5 percent, criteria for borrow material were used to establish a-values because, at these percentages, it is reasoned that the aggregate acts more like a subgrade soil. At 10 percent added fines, a-values were determined using both criteria because 10 percent added fines is thought to represent a borderline situation. Tables 9 and 10 give summaries of the a-value determinations for use in the AASHTO equation.

The effect of added fines on the life of the pavement section under consideration is defined in terms of a pavement life ratio (PLR). PLR is defined as the allowable number of 18-kip (80-kN) equivalent axle loads for a given percentage of added fines divided by the allowable axle loads at 0 percent added fines. The U.S. Forest Service *(20)* uses the AASHTO method to determine the allowable number of axle loads. For the pavement section shown in Figure 1, the results of the analysis, including pavement life ratios, are given in Table 11.

TABLE 10 DETERMINATION OF a-VALUES AND CORRESPONDING STRUCTURAL EQUIVALENCY RATIOS BASED ON U.S. FOREST SERVICE a_3-VALUE CRITERIA *(24)*

Criteria	S (%) 10	12	19.5
Fractured aggregate	0.06	0.06	0.06
Plasticity, PI less than 2	0.01	0.01	0.00
Quality	0.01	0.01	0.00
P 200: 0–10	0.01	0.00	0.00
P 4: 25–60	0.01	0.01	0.01
Composite a-value	0.10	0.09	0.07
a-value SER	0.714	0.643	0.500

Note: Subgrade CBR = 8, which is equivalent to a = 0.07; a-value at S = 19.5 percent is set equal to the a-value of the subgrade.

Allowable axle loads are computed for BOUSS and ELSYM5 using fatigue criteria from Monismith, cited by Yoder and Witczak *(16)*, and the Asphalt Institute, cited by Bell *(15)*. These equations are

Monismith equation: $N = 0.000000516\ p_{R1}^{-3.322}$ (4)

The Asphalt Institute equation: $N = 0.00000111\ p_{R1}^{-3.29}$ (5)

Both of these equations are based on the following assumptions, which are considered to be representative of a typical asphalt concrete mix:

1. Asphalt content is 6 percent by weight,
2. Air void content is 5 percent by volume,
3. Resilient modulus of mix is 400,000 psi (2 760 000 kPa),
4. p_{R1} is the radial strain at the base of the bituminous concrete layer, and
5. N is the allowable number of 18-kip (80-kN) equivalent axle loads.

Table 12 gives a summary of the results of the calculations using BOUSS, and Table 13 gives similar information for ELSYM5. The Monismith and the Asphalt Institute methods differ in the number of allowable axle loads permitted for a given value of S and radial strain (p_{R1}). However, in terms of PLR, each method gives nearly identical results.

When the results of the three methods are compared (Table 14), it can be seen that each method gives a different estimate of pavement life. However, the general trend is the same for all methods; PLR decreases as the percentage of added fines increases. BOUSS generally gives the lowest estimate of pavement life, and AASHTO gives the highest estimate. However, AASHTO is in close agreement with ELSYM5. Because AASHTO is in relatively close agreement with ELSYM5, the a-values determined using the U.S. Forest Service criteria can be used to represent the effects of added fines. In terms of use

TABLE 11 PAVEMENT LIFE RATIOS FOR U.S. FOREST SERVICE METHOD

S (%)	a_2 Value	SER	SN	W	PLR
0	0.14	1.000	2.00	48,600	1.000
2	0.14	1.000	2.00	48,600	1.000
4	0.13	0.928	1.96	43,000	0.885
6	0.12	0.857	1.92	37,800	0.778
8	0.11	0.786	1.88	33,500	0.689
10	0.10	0.714	1.84	29,400	0.605
12	0.09	0.643	1.80	25,900	0.532
19.5	0.07	0.500	1.72	19,800	0.407

Notes:

SN = Structural number

$SN = a_1D_1 + a_2D_2$

$a_1 = 0.36$

$D_1 = 4$ inches

$D_2 = 4$ inches

W = Allowable number of 18 kip (80 kN) equivalent axle loads.

Subgrade CBR = 8.

TABLE 12 PAVEMENT LIFE RATIOS (PLRs) FOR BOUSS METHOD

S (%)	E2 (psi)	SER	P_{R1} (Microstrain)	N_M	PLR	N_{TAI}	PLR
0	37,500	1.000	383.8	114,700	1.000	365,500	1.000
2	33,225	0.886	415.6	88,100	0.768	281,300	0.770
4	37,500	1.000	383.8	114,700	1.000	365,500	1.000
6	37,500	1.000	383.8	114,700	1.000	365,500	1.000
8	19,750	0.527	571.7	30,500	0.266	98,500	0.270
10	18,500	0.493	593.6	26,900	0.235	87,000	0.238
12	17,250	0.460	617.6	23,600	0.206	76,400	0.209
19.5	12,500	0.333	735.7	13,200	0.115	43,000	0.118

Notes:

P_{R1} = Radial strain at the base of the bituminous concrete layer (Fig. 1).

N_M = Allowable number of 18 kip (80 kN) equivalent axle loads, using Monismith's fatigue criteria.

N_{TAI} = Allowable number of 18 kip (80 kN) equivalent axle loads, using The Asphalt Institute fatigue criteria.

TABLE 13 PAVEMENT LIFE RATIOS (PLRs) FOR ELSYM5 METHOD

S (%)	E2 (psi)	SER	P_{R1} (Microstrain)	N_M	PLR	N_{TAI}	PLR
0	37,500	1.000	333.2	183,500	1.000	581,900	1.000
2	33,225	0.886	347.7	159,300	0.868	505,800	0.869
4	37,500	1.000	333.2	183,500	1.000	581,900	1.000
6	37,500	1.000	333.2	183,500	1.000	581,900	1.000
8	19,750	0.527	403.1	97,500	0.531	311,000	0.534
10	18,500	0.493	409.4	92,600	0.505	295,500	0.508
12	17,250	0.460	415.8	88,000	0.480	280,800	0.483
19.5	12,500	0.333	443.1	71,200	0.388	227,800	0.391

Notes:

P_{R1} = Radial strain at the base of the bituminous concrete layer (Fig. 1).

N_M = Allowable number of 18 kip (80 kN) equivalent axle loads, using Monismith's fatigue criteria.

N_{TAI} = Allowable number of 18 kip (80 kN) equivalent axle loads, using The Asphalt Institute fatigue criteria.

in pavement design, the following are recommended PLRs for use in comparing alternative designs:

S	*F*	*PLR*
0–6	5.5–11.5	1.00
8	13.5	0.53
10	15.5	0.50
12	17.5	0.48
19.5	25.0	0.39

Potential Cost Savings of Using Geotextiles

Two methods are used to illustrate the potential benefits of using geotextiles as a separation layer. They involve determining *(a)* the amount of additional aggregate base needed in the original design when geotextiles are not used or *(b)* the depth of a bituminous concrete overlay needed after base contamination occurs.

The amount of additional aggregate base needed, when geo-

TABLE 14 COMPARISON OF DESIGN PAVEMENT LIFE RATIOS

S (%)	E2 (psi)	a_2 Value	AASHTO PLR	BOUSS PLR	ELSYM5 PLR
0	37,500	0.14	1.000	1.000	1.000
2	33,225	0.14	1.000	0.768	0.868
4	37,500	0.13	0.885	1.000	1.000
6	37,500	0.12	0.778	1.000	1.000
8	19,750	0.11	0.689	0.266	0.531
10	18,500	0.10	0.605	0.235	0.505
12	17,250	0.09	0.532	0.206	0.480
19.5	12,500	0.07	0.407	0.115	0.388

Notes:

AASHTO = U.S. Forest Service method (24).

BOUSS = Boussinesq Method of Equivalent Thickness (15).

ELSYM5 = Elastic layer method (17).

TABLE 15 BASE THICKNESS AND ASSOCIATED COST SAVINGS USING GEOTEXTILES, AASHTO METHOD *(24)*

	S (%)					
	0–4	6	8	10	12	19.5
Base Thickness (in.)						
Without geotextile						
a_2	0.14	0.12	0.11	0.10	0.09	0.07
D_2 (full intrusion)	4.0	5.0	5.5	6.0	6.5	8.0
D_2 (partial intrusion)	4.0	4.5	5.0	5.0	5.5	6.0
With geotextile, D_2	4.0	4.0	4.0	4.0	4.0	4.0
Cost Savings ($ per lineal foot)						
Additional aggregate cost						
Full intrusion		1.39	2.08	2.78	3.47	5.56
Partial intrusion		0.70	1.39	1.39	2.08	2.78
Geotextile cost		0.83	0.83	0.83	0.83	0.83
Cost savings						
Full intrusion		0.56	1.25	1.95	2.64	4.73
Partial intrusion		(0.13)	0.56	0.56	1.25	1.39

Note: D_2 = depth of aggregate bases rounded up to the nearest ½ in. Full intrusion assumes intrusion will occur throughout D_2. Partial intrusion assumes intrusion will be confined to first 4 in. of D_2. a_2 = 0.14 for original aggregate base and for situation with geotextile separator. Additional aggregate computed assuming a double-lane road 26 ft shoulder to shoulder at the top of pavement and having a 30-ft subgrade. Aggregate base cost = $15/yd^3. Geotextile cost = $0.75/yd^2.

textiles are not used, is illustrated using the cross section shown in Figure 1 and the AASHTO equation *(20)*. Table 15 gives the additional aggregate needed for various levels of percentage of added fines, as well as the estimated cost savings that may accrue from the use of geotextiles as an alternative to additional aggregate base. Two intrusion conditions are assumed: full intrusion of the aggregate base and partial intrusion. The former assumes that intrusion occurs throughout the depth of the base, whereas the latter assumes that intrusion is confined to the first 4 in. At 12 percent added fines, cost savings of up to $2.64 per lineal foot of roadway could accrue as a result of using geotextiles as a separation mechanism. This level of added fines is typical of some National Forest roads *(19)*. Using the maximum laboratory-determined level of 19.5 percent added fines, cost savings of up to $4.73 per lineal foot of roadway could occur.

Another way to illustrate the benefits of using geotextiles is to determine the depth of additional bituminous concrete needed during initial construction (or after contamination occurs). This is also illustrated using the AASHTO procedure *(20)*. Table 16 gives the amount of overlay needed using AASHTO *(20)* for the various levels of percentage of added

TABLE 16 COST SAVINGS USING GEOTEXTILES AS AN ALTERNATIVE TO ADDITIONAL BITUMINOUS CONCRETE, AASHTO METHOD *(24)*

S % =	0 to 2	4	6	8	10	12	19.5
	(a) Asphalt Surface Thickness, in.						
D_1 Without Geotextile	4.00	4.25	4.25	4.50	4.50	4.75	5.00
D_1 With Geotextile	4.00	4.00	4.00	4.00	4.00	4.00	4.00
D_1 Savings	0	0.25	0.25	0.50	0.50	0.75	1.00
	(b) Incremental Cost Savings, $ per lineal ft						
Overlay Cost		1.21	1.21	2.41	2.41	3.61	4.81
Geotextile Cost		0.83	0.83	0.83	0.83	0.83	0.83
Cost Savings Using Geotextiles		0.38	0.38	2.03	2.03	2.78	3.98

Notes:
D_1 = Depth of bituminous concrete with a_1 = 0.36.
Overlay assumed to be for a double lane road, 26 ft shoulder to shoulder.
Bituminous concrete cost = $60/cy.
Geotextile cost = $0.75/sy.

TABLE 17 U.S. FOREST SERVICE REQUIREMENTS FOR SEPARATION GEOTEXTILES *(25)*

Test Standard	Property
Geotextile properties	
Grab tensile strength (ASTM D1682)	110 lb min
Grab tensile elongation (ASTM D1682)	15% min
Equivalent opening size (U.S. standard)	
Nonwoven	20–100
Woven	20–70
Bursting strength[a] (ASTM D751)	200 lb min
Puncture strength[a] (ASTM D751)	42 lb min
Percentage open area	
Nonwoven	None specified
Woven	< 4%
Permeability	0.001 cm/sec min
Weight	4 oz/yd^2 min
Thickness	15 mils min
Soil subgrade properties	
CBR	3 min
Vane shear strength	10 psi min
Particle size of aggregate base	2 in. max

[a]Unaged fabric.

fines, as well as associated cost savings. This method indicates that a potential cost savings of $2.78 per lineal foot of roadway can accrue when the contaminated aggregate base contains up to 12 percent added fines. At 19.5 percent added fines, the savings could reach $3.98 per lineal foot of roadway. For pavement sections with thicker base layers (8 to 12 in.), it is possible that even greater cost savings could be realized.

Performance Objectives for Separation Geotextiles

This study did not evaluate the physical properties of geotextiles needed to achieve the performance objectives of a separation layer. Properties required in the 1985 U.S. Forest Service Standard Specification are given in Table 17 *(21)*.

Research by others to date suggests that the amount of contamination depends on percentage of open area, porosity, effective opening size, and thickness of the geotextile *(4, 5, 7, 8)*. Performance criteria that need to be established for separation geotextiles are those that limit the amount of added subgrade fines to an acceptable level. For the situation tested (F_0 = 5.5), the geotextile needs to limit the amount of added subgrade fines (S) to 2.5 percent to maintain drainage and to 6 percent to maintain stiffness. These criteria need to be evaluated in terms of the depth and gradation of aggregate base used because these factors influence whether full or partial intrusion is experienced.

Geotextiles used for separation must also be able to withstand the effects of abrasion during and after construction. Following construction, the geotextile should also be able to withstand compressive strains in the vertical direction and tensile strains in the horizontal direction.

SUMMARY

A laboratory study to evaluate the effects to added subgrade fines on the resilient modulus of an aggregate base has been described. The aggregate tested was a 1-in.-minus crushed aggregate with 5.5 percent passing the No. 200 (0.075-mm) sieve. Subsequent tests were conducted after adding 2, 4, 6, 8, and 19.5 percent subgrade fines to the original aggregate. The testing program showed that the resilient modulus of the aggregate-subgrade mixture increased as the percentage of added fines increased; a peak in resilient modulus occurred at 6 percent added fines. At 8 percent added fines, a dramatic drop in resilient modulus was experienced. This indicates that, from a stiffness standpoint, up to 6 percent added fines can be tolerated when the initial aggregate has 5.5 percent passing the No. 200 (0.075-mm) sieve.

When the effect of subgrade intrusion is evaluated, maintaining adequate permeability within the aggregate base also needs to be considered. U.S. Forest Service specifications *(13)* allow up to 8 percent fines in the aggregate produced for a construction contract. If it is assumed that this is to be the upper limit for proper drainage, the amount of added fines needs to be limited to 2.5 percent if the initial aggregate has 5.5 percent fines. Thus it appears that limiting subgrade intrusion for drainage purposes may take priority over limiting subgrade intrusion for stiffness purposes.

The effect of subgrade intrusion is a reduced modulus of the aggregate base and a shorter pavement life. The life of a pavement can be extended by taking this into account during design by providing either a thicker aggregate base course or a thicker bituminous concrete layer. A cost-effective alternative is the use of geotextiles as a separation layer. The potential cost savings can reach $3 to $4 per lineal foot of roadway, depending on the amount of added fines.

Available test data for geotextiles in separation applications have several limitations. One of these is the lack of a standardized test procedure for measuring soil contamination values in the laboratory. Additional research is also needed to quantify the specific geotextile properties that limit intrusion. Finally, actual geotextile installations need to be monitored to evaluate their effectiveness under field conditions.

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