with an increase in total temperature. The subgrade modulus is only affected by the subgrade moisture content; the higher the water content, the lower the subgrade modulus. For the subbase modulus, no single factor can be considered as significant, namely, the subbase modulus remains almost constant throughout the test facility and the testing period.

SUMMARY

Based on the results of a theoretical analysis, a method for evaluating the in situ moduli of pavement constituent layers from road-rater deflection basins was developed. By using this method, the moduli of pavement layers at the Pennsylvania Transportation Research Facility were evaluated.

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Fabric Use in Low-Deformation Transportation Support Systems

M. R. THOMPSON AND L. RAAD

The feasibility of using fabrics in the construction or rehabilitation of conventional transportation support systems such as secondary roads or track beds was considered. Structural improvement concepts were analyzed. Several theoretical behavior models (ILLI-PAVE, LSTRN3, BISAR, and a simplified confinement model) were used in the structural analyses of soil-fabric-aggregate (SFA) systems. Structural improvement effects, as evidenced by ILLI-PAVE, calculated vertical stress distributions, and vertical deflections in a conventional SFA system are not achieved, thus previous experimental data are confirmed. However, BISAR structural analyses of a typical SFA system indicated the beneficial effects of no slippage conditions at the aggregate-subgrade interface. A simplified confinement model indicated that, if significant permanent deformation is developed in an SFA system, a substantial percentage increase in confinement can be developed. Proposed SFA behavior mechanisms indicated that a stage construction sequence for low-traffic-volume roads and track systems provided for use of the full potential (separation and structural improvement) of fabrics in SFA systems.

Laboratory studies and field performance data have shown that soil-fabric-aggregate (SFA) systems are effective for soft soil (large rut-depth development) applications. Equivalent performance (SFA - conventional aggregate layer construction) can be achieved with a reduced aggregate thickness if a fabric is installed at the soil-aggregate interface.

The success of SFA systems for soft soil applications has led to the development of increasing interest in the potential of fabric use in conventional transportation support systems (e.g., railroads, highway pavements, and airfield pavements). The major difference between conventional transportation support and SFA systems constructed over soft soils is the magnitude of tolerable levels of rut development and surface deflection. Permissible levels of rutting and resilient deflection for conventional transportation support systems are on the order of 1.5 and 0.500 in (38 and 12.7 mm), respectively. Rut depths on the order of 3-5 in (76-127 mm) and resilient deflections in excess of 1 in (25.4 mm) are commonly incurred in SFA systems on soft soils.

The influence of fabric on the structural behavior and performance of low-deformation (SFA) systems is not well established. The purpose of this paper is to investigate potential mechanisms of improvement and thereby determine the feasibility of using fabrics in the construction or rehabilitation of conventional transportation support systems such as primary and secondary roads and trackbeds.

EFFECTS OF STRUCTURAL IMPROVEMENT

Fabrics are thin and exhibit resistance to applied tensile forces but little resistance to compressive forces. To simulate this structural behavior, the fabric should be treated as an element that can carry tension but no compression.

Fabric stiffness is defined as the force required to produce a unit displacement. If the given fabric is replaced by a transformed section of the same stiffness, the modulus of the transformed section is given by

$$E_E = E_F T_F / T_E \qquad (1)$$

where E_F and T_F are the modulus and thickness of original fabric and E_E and T_E are the modulus and thickness of the transformed section. The transformed section concept was used (1) to demonstrate how the responses of a soil-fabric system are affected if the original fabric is replaced by an equivalent transformed section. An elastic-based finite-element computer model (LSTRN 3) (2) that incorporates truss type elements (elements can carry tension but not compression) was used. Results of analysis indicate that lateral strains in the fabric, vertical subgrade stresses and strains, and surface deflections are not affected if the transformed section has a thickness that does not exceed 12 times the thickness of the original fabric.

The transformed section concept was used in available nonlinear finite element (ILLI-PAVE) and linear elastic (BISAR) programs to analyze SFA systems.

Resilient Behavior Considerations

The potential effect of a fabric layer on a SFA system was considered by using ILLI-PAVE (a stress-dependent finite-element model developed at the University of Illinois). A typical low-traffic-volume road section [8 in (203 mm) of crushed stone] and a very soft subgrade were assumed. The very soft subgrade condition accents any beneficial effects of the fabric (increased fabric tensile forces are developed at high deflections). ILLI-PAVE assumes full friction (no slip) at all material interfaces. Fabric properties [modulus = 30 lb/1 percent (0.13 kN/1 percent), Poisson's ratio = 0.2] were used. Subgrade and granular resilient properties are shown in Figure 1. Subgrade shear strength (cohesion) was 3 $\mathrm{lbf/in^2}$ (20.7 kPa). A ϕ angle of 40° was assumed for the granular material. Pavement loading was a 9-kip (40-kN) wheel load and 80 $\mathrm{lbf/in^2}$ (551 kPa) tire pressure.

Results of analysis show that there is no fabric effect on vertical stress distribution, failure zones in the granular base, and deflection pattern (Figure 2) in the pavement section.

Previous experimental studies (3-6) and data from this study have demonstrated that the resilient behavior of SFA systems is not significantly influenced by the presence of a fabric. The ILLI-PAVE data confirm that finding. Note that the surface deflection of the pavement was only 0.070 in (1.78 mm). Such a small deflection is not sufficient to mobilize the fabric tensile reinforcement effect.

Slippage Considerations

The BISAR elastic layered program can accommodate slippage between layers. The crushed stone-fabric section was analyzed for no slippage and complete slippage. Comparative deflection data for the two conditions are shown in Figure 3.

Slippage at the interface between the granular base and subgrade increases the resilient deformations of the pavement, which would hasten its rate of deterioration. Use of fabric at the interface should reduce the slippage effect and therefore improve performance. Reduction of resilient deflections is most pronounced in the subgrade and could be as much as 30 percent.

Figure 1. Resilient properties of subgrade and granular materials.

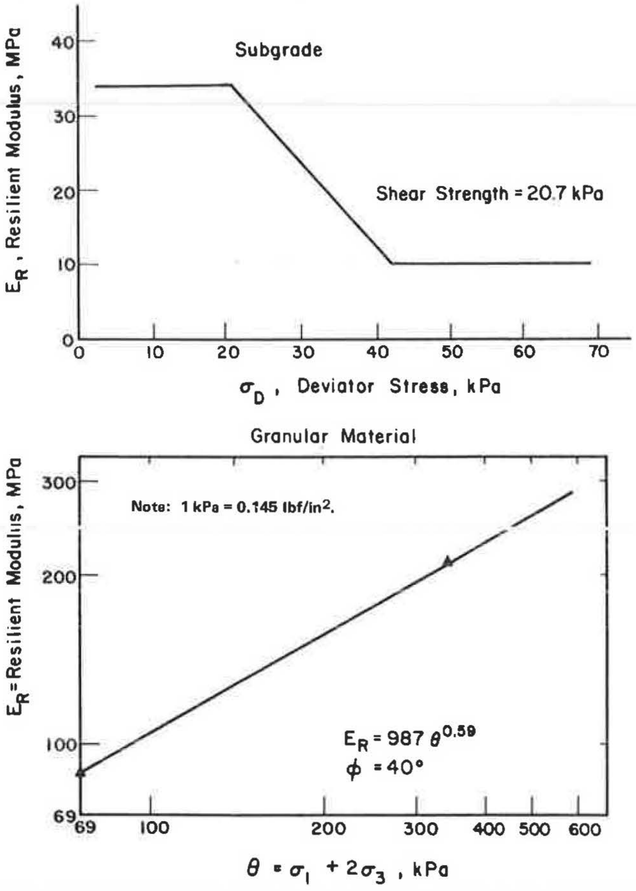


Figure 2. Fabric effect on vertical deflections (ILLI-PAVE model).

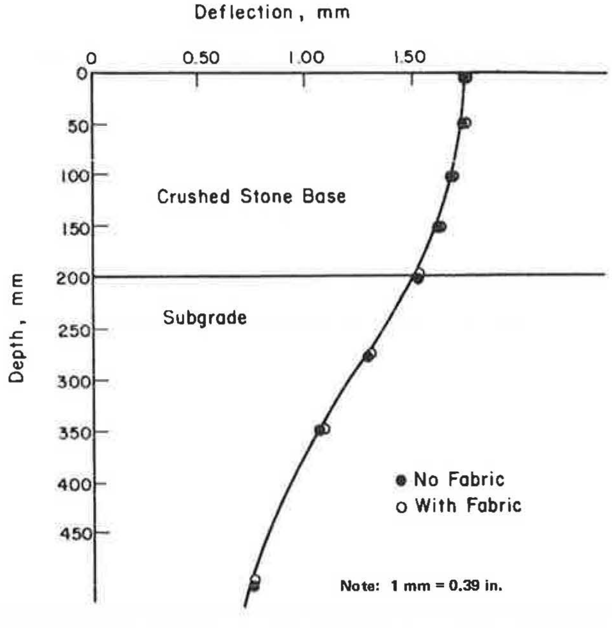


Figure 3. Effect of slippage on vertical deformations (BISAR model).

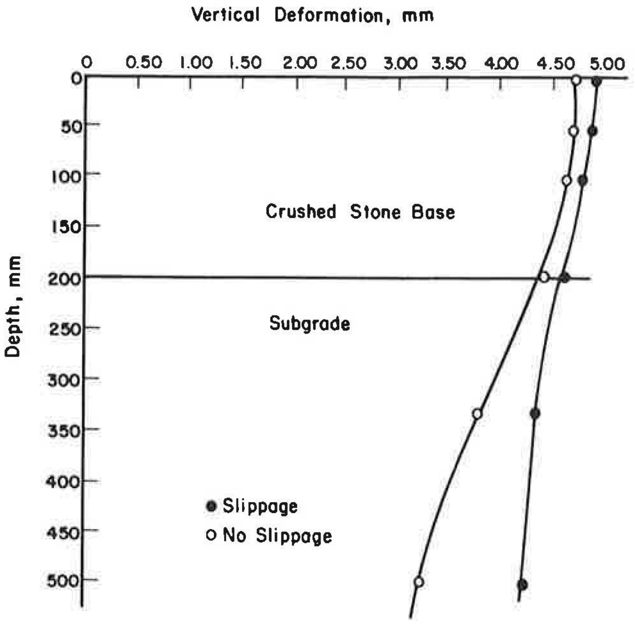
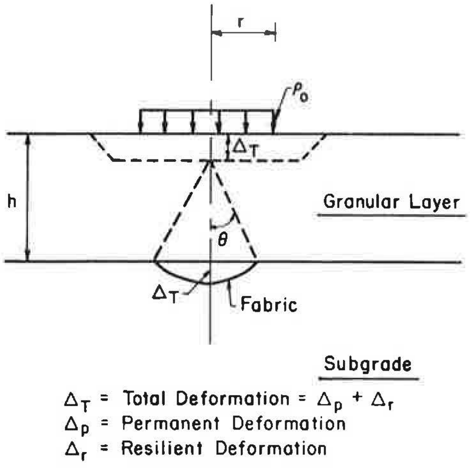


Figure 4. Increased confinement-effect model.



Increased Confinement Considerations

As the SFA system deforms, increased lateral confining pressures develop due to the horizontal component of the normal stresses at the fabric-subgrade interface. If the fabric-subgrade interface is level, no horizontal component of the normal stress is mobilized.

Assume that the aggregate layer is incompressible and the deformed shape of the fabric is approximated by a circular arc, as shown in Figure 4. If we ignore the confining effect of shear stresses and tensile stresses in the fabric (they act in opposite directions), the following can be demonstrated:

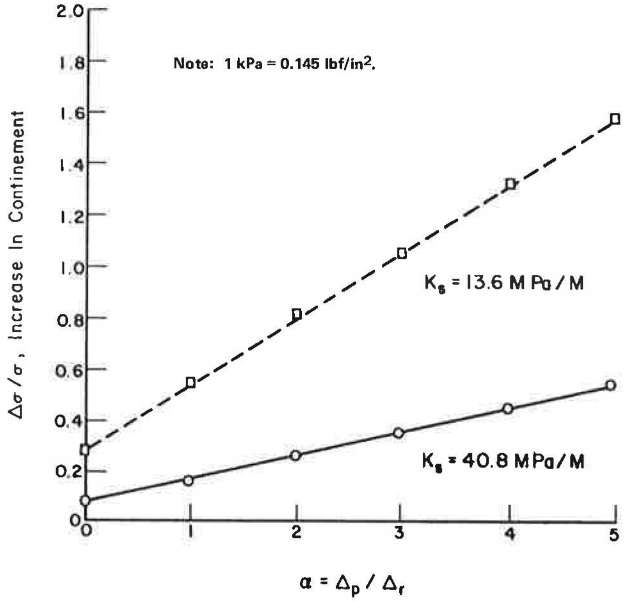
$$\Delta\sigma/\sigma = [P_o(r)/K_sK_oh\,(h + r)]\,(1 + \alpha) \qquad (2)$$

where

$$\alpha = \Delta_p/\Delta_r \qquad (3)$$

P_o = applied surface pressure;
r = radius of loaded area;

Figure 5. Increase in confinement for SFA systems.



K_s = modulus of subgrade reaction;
k_o = coefficient of earth pressure at rest;
h = thickness of granular layer;
$\Delta\sigma/\sigma$ = increase in confinement at interface due to deformation of fabric, expressed in terms of original confinement (σ) before fabric deforms;
Δ_p = permanent deformation; and
Δ_r = resilient deformation.

For example, for K_s = 50 (lbf/in^2)/in (13.5 MPa/m), h = 6 in (152 mm), r = 6 in (152 mm), P_o = 80 lbf/in^2 (551 kPa), and K_o = 0.5. Then, $\Delta\sigma/\sigma = 0.27\ (1 + \alpha)$.

For K_s = 150 (lbf/in^2)/in (40.7 MPa/m). Then $\Delta\alpha/\sigma = 0.09\ (1 + \alpha)$.

$\Delta\sigma/\sigma$ relations represented by the last two calculations are shown in Figure 5. Note that $\Delta\sigma/\sigma$ improvements on the order of 80 percent are realized for soft subgrade conditions and α values (Δ_p/Δ_r) of approximately two. It is apparent that the increased confinement effects are accentuated for the soft subgrade condition.

Small increases in confining pressure significantly improve the shear strength, stiffness, and permanent deformation behavior of granular materials. The improved characteristics of the granular material should contribute to better SFA system performance.

PERFORMANCE CONSIDERATIONS

Although no significant improvement is achieved for low-deformation SFA systems, larger deformations [greater than 0.5 in (12 mm)] due to weakened subgrade conditions or load repetitions could mobilize the tensile reinforcement in the fabric and reduce the subgrade stresses (7). Moreover, the development of larger deformations could increase the confinement of the base, as described earlier in this paper. Such behavior mechanisms in terms of increased tensile reinforcement and base confinement indicate the validity of a stage-construction concept for SFA systems. The concept can be used for low-traffic-volume roads and track systems. The SFA system for low-traffic-volume roads is not immediately surfaced.

Following the first period of weak subgrade support and after rut development has stabilized, the SFA system surface is graded (with or without the addition of aggregate) and smoothness is restored. The SFA system is then surfaced (probably with a surface treatment). If necessary, the SFA system could be surfaced initially and then resurfaced following the period of development of rut depth.

A similar approach is possible for applications of track systems. Following initial development of permanent deformation in the ballast-subgrade system, the track could be resurfaced, thus a desirable level of track geometry could be restored. Subsequent development of permanent deformation would be minimized because of the structural improvement affected by the fabric.

The construction procedure in stages permits the use of the full potential of the fabric (separation and structural improvement). Note that to maximize structural improvement effects it is necessary to develop significant permanent deformation in the fabric.

SUMMARY

Structural improvement effects, as evidenced by ILLI-PAVE-calculated vertical stress distributions and vertical deflections in a conventional SFA system, are not achieved for the small permanent deformations typically experienced, thus previous experimental data are confirmed. BISAR structural analyses of a typical SFA system indicated the beneficial effects of no-slippage conditions at the aggregate-subgrade interface (it is postulated that fabric will decrease slippage at the interface).

A simplified confinement model indicated that, if significant permanent deformation is developed in an SFA system, a substantial percentage increase in confinement can be developed. This effect is most pronounced for soft subgrade conditions.

Fabric can be used beneficially in the construction or rehabilitation of the transportation support system in many situations. The most-promising applications are unsurfaced aggregate layers (low-traffic-volume roads and track systems). We postulate that a construction procedure in stages (surface treatment of an aggregate road following the initial period of reduced subgrade support) would be feasible for low-traffic-volume roads. The concept of construction in stages also can be applied to track system problems.

ACKNOWLEDGMENT

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New Interpretation of Plate-Bearing Tests

R. BUTTERFIELD AND M. GEORGIADIS

A new procedure for interpreting plate-bearing tests is proposed that allows the complete nonlinear pressure versus displacement curve to be described in terms of stiffness parameters that are quite independent of the plate size. The nonlinear model incorporates shear springs in between the usual Winkler compression springs and requires conventional plate tests on plates of two different sizes in order to determine the two stiffness contributions. The predictive capacity of the procedure has been demonstrated by tests on both London clay and Kaolin with square plates that span an 8:1 size range as well as in situ tests from the literature. Examples are also included to illustrate its application to the analysis of soil-supported, very flexible elastic beams.

The conventional plate-bearing test, in which a rigid plate (area A) is pushed vertically into the ground at a constant rate, is a convenient way to generate information on the stiffness and load capacity of such a system. The load (Q) (or pressure, q = Q/A) versus displacement (w) curves obtained are usually of the form shown in Figure 1, which depicts the mean results of a series of circular plate tests on a remolded London clay bed ($\bar{w}_L$ = 65 percent; $\bar{w}_p$ = 23 percent; $\bar{w}$ = 25 ± 1 percent; and $c_u \simeq 97$ kN/m²). Each of the curves shown is, in fact, a very close, best-fit representation of the experimental results by using the empirical equation for a plate of diameter D.

$$q/q_u = Q/Q_u = 1 - \exp[-(K_o - K_f)(w/D)] + K_f(w/D) \quad (1)$$

where

$K_o = k_o D/q_u$,
$K_f = k_f D/q_u$,