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Assessment of interface shear growth from measured geosynthetic strains in a reinforced pavement subject to repeated loads

Perkins, S.
Montana State University

Svanø, G.
SINTEF Civil and Environmental Engineering

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ABSTRACT: The principal effect of reinforcement in base-reinforced flexible pavements is to provide lateral confinement of the aggregate layer. Lateral confinement arises from the development of interface shear stresses between the aggregate and the reinforcement, which in turn transfers load to the reinforcement. The interface shear stress present when a traffic load is removed continues to grow with traffic load applications, meaning that the lateral confinement of the aggregate increases with increasing load applications. Finite element pavement response models can be formulated to account for the effect of increasing lateral confinement provided information on this growth relationship is available. Data is presented from field-scale test sections showing the development of reinforcement strain with traffic pass. Interface shear stress is related to reinforcement strain through appropriate theoretical considerations. The application of this information to reinforced pavement analysis within the context of finite element response models is discussed.

1 INTRODUCTION

Experimental and theoretical studies on reinforcement of aggregate base layers in flexible pavements using geosynthetics have shown that the principal effect of the reinforcement is to provide lateral confinement of the aggregate (Bender et al., 1978; Kinney et al., 1982; Perkins, 1999; Perkins and Edens, 2002). Lateral confinement is due to the development of interface shear stresses between the aggregate and the reinforcement, which in turn transfers load to the reinforcement. As a cycle of traffic load is applied, there is both a resilient or recoverable shear stress and a permanent shear stress that exists when the traffic load is removed. The permanent interface shear stress continues to grow as repeated traffic loads are applied, meaning that the lateral confinement of the aggregate base layer becomes greater with increasing traffic load repetitions.

Modern pavement response models, such as finite element models, can be formulated to account for the effect of increasing lateral confinement with increasing traffic load repetitions. Information is needed, however, to describe the relationship between increasing permanent interface shear stress and traffic pass level. This information can be obtained from field data by examining tensile strains developed in the reinforcement as a function of traffic passes and relating this development to interface shear stress through appropriate theoretical considerations.

2 FIELD DATA

Previously reported test sections (Perkins, 1999) were constructed to provide stress, strain and displacement response data for base reinforced flexible pavements. Data presented below is obtained from these test sections having a nominal 75 mm thick asphalt concrete layer, a 300 mm base aggregate layer, a geosynthetic placed between the base and the subgrade and a subgrade with a CBR strength of 1.5%. The test sections were constructed in a concrete box measuring 2 m by 2 m in plan and 1.5 m in depth. Loading was provided by applying a 1.5 sec period cyclic load of 40 kN to a 305 mm diameter plate.

As demonstrated and discussed in a previous paper (Perkins, 1999), extensional horizontal strain is developed at the bottom of the base aggregate layer under the area of the load, as shown for a typical test section in Figure 1, where extensional strain is taken as positive. The magnitude of strain is seen to increase with increasing traffic load repetitions. Relative motion is created between the aggregate and the relatively stiff reinforcement, which in turn creates interface shear stress. This shear stress induces load and strain

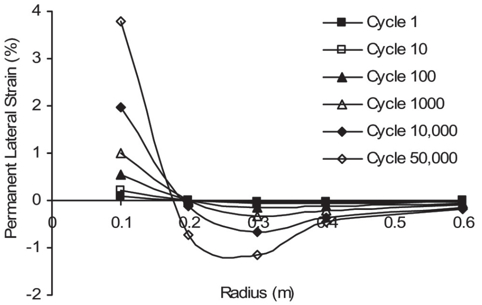

Figure 1. Development of lateral strain in the bottom of a base aggregate layer with traffic load repetitions.

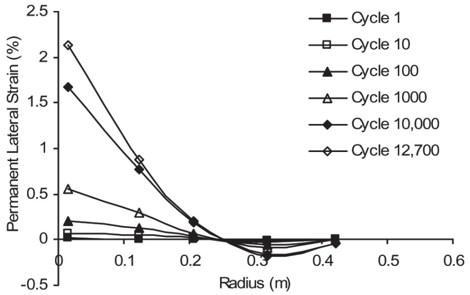

Figure 2. Development of lateral strain in a reinforcement layer with traffic load repetitions.

in the reinforcement with the strain distribution shown in Figure 2 for a typical test section and where tensile strain is taken as positive.

Reinforcement strain was measured from bonded resistance strain gauges attached to ribs of the geogrid. Details of the bonding, calibration and protection procedures have been provided elsewhere (Perkins et al., 1997). Reinforcement strain distributions similar to those shown in Figure 2 have been demonstrated in other test section studies (Fannin and Sigurdsson, 1996; Haas et al., 1988; Miura et al., 1990).

Dynamic (resilient), ε_r, and permanent strain, ε_p, data was collected from the strain gauges attached to the reinforcement sheets. Resilient strain for each strain gauge was nearly constant for all traffic pass levels. The permanent strain was normalized by the resilient strain for the corresponding traffic pass and plotted against a normalized traffic pass level. Expressing permanent reinforcement strain as a function of these variables is used to relate reinforcement strain to interface shear stress, as will be shown in the following section.

Normalized traffic pass level ($N/N_{25\ mm}$) is the actual traffic pass level divided by the number of traffic passes necessary to achieve 25 mm of permanent surface deformation. Figure 3 shows results for a typical reinforced test section. Measurements of strain were obtained from strain gauges placed in the machine

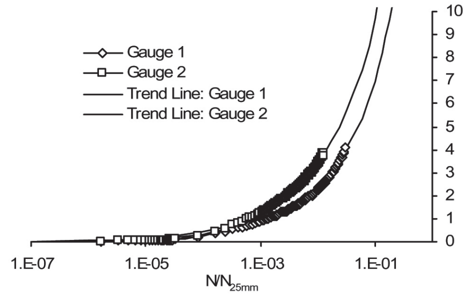

Figure 3. Permanent over radial strain versus normalized traffic load passes for section 1.

(gauge 1) and cross-machine directions (gauge 2) of the geosynthetic and were oriented in a direction radial to the centerline of the load plate. The center point of the gauge was between 15 to 20 mm from the centerline of the test section.

Examination of results from test sections with other reinforcement products indicates that the ratio of permanent to resilient strain differs between reinforcement products and between different material directions. This relationship can be approximated by a logarithmic curve given by Equation 1 and shown as a "Trend Line" for each gauge in Figure 3. Curve fitting parameters *A* and *B* are listed in Table 1 for three test sections with properties described earlier in this section. Sections 1, 2 and 3 contained Tensar BX1100 geogrid, Tensar BX1200 geogrid and Amoco 2006 geotextile, respectively.

$$\log\left(\frac{\varepsilon_p}{\varepsilon_r}\right) = \log(A) + B\log\left(\frac{N}{N_{25\,\mathrm{mm}}}\right) \quad (1)$$

Table 1. Parameters *A* and *B* for Equation 1 for three reinforced test sections.

Test Section	Strain Gauge	*A*	*B*
1	1	18	0.37
1	2	63	0.45
2	1	20	0.46
2	2	28	0.46
3	1	3.0	0.18
3	2	4.3	0.18

3 THEORY

In order to relate measured reinforcement strain to interface shear stress, an infinitesimal axisymmetric element of the reinforcement is considered (Figure 4). The interface shear stress from relative movement of the base is considered as a unit shear stress, τ. Force equilibrium in the radial direction for an infinitesimal element is given by Equation 2.

$$\frac{d\sigma_r}{dr}\,dr\,rd\theta + \sigma_r dr\,d\theta + \tau\,dr\,rd\theta - \sigma_\theta\,drd\theta = 0 \quad (2)$$

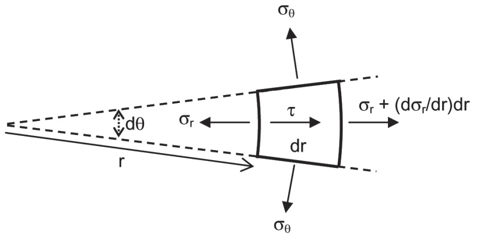

Figure 4. Infinitesimal reinforcement element.

Dividing Equation 2 by rdrd θ yields Equation 3.

$$\frac{d\sigma_r}{dr} + \frac{\sigma_r - \sigma_\theta}{r} + \tau = 0 \tag{3}$$

In cases where it is reasonable to assume that the difference in stresses between the radial and the ring directions is small, such as in the vicinity of the centerline of the test section, Equation 3 can be approximated by Equation 4.

$$\frac{d\sigma_r}{dr} + \tau = 0 \tag{4}$$

Separating and integrating Equation 4 produces Equation 5.

$$\sigma_r \int \tau \, dr \tag{5}$$

If the reinforcement is assumed to correspond to a linear elastic material with an elastic modulus in any principal direction given by E, then the stress σ_r can be replaced by εE, where ε is the strain in the reinforcement in the radial direction. Equation 5 can then be expressed in terms of strain for the dynamic (resilient) state, ε_r, when a resilient interface shear stress, τ_r, acts on the reinforcement (Equation 6) and for the state when permanent strain, ε_p, exists in the reinforcement when the pavement load is removed and a permanent shear stress, τ_p, acts on the reinforcement (Equation 7).

$$\varepsilon_r = \frac{\int \tau_r \, dr}{E} \tag{6}$$

$$\varepsilon_p = \frac{\int \tau_p \, dr}{E} \tag{7}$$

If it is assumed that the shape of the functions for τ_r and τ_p are identical, then Equations 6 and 7 can be combined to yield Equation 8.

$$\tau_p = \tau_r \frac{\varepsilon_p}{\varepsilon_r} \tag{8}$$

Equation 8 allows for the permanent shear stress on the interface to be estimated for any traffic pass level by using Equation 1 to estimate the permanent to resilient reinforcement strain ratio ($\varepsilon_p/\varepsilon_r$) provided the resilient or dynamic interface shear stress, τ_r, can be determined. Techniques for making this determination are discussed in the following section.

4 APPLICATION

Equations 1 and 8 are useful for reinforced pavement analysis when a numerical response model, such as a finite element model, is used. A properly formulated finite element model of a reinforced pavement can be used to determine the distribution of interface shear stress between the reinforcement and the surrounding materials when a single traffic load is applied. The resulting interface shear stress distribution is regarded as the dynamic (resilient) shear stress, τ_r. Values of τ_r are then used in Equation 8 along with Equation 1 to determine the permanent interface shear stress distribution for any level of traffic passes.

As an example, a finite element response model described by Eiksund et al., 2002 was analyzed. This model replicates conditions in the test sections described above and uses linear elastic material properties for all layers. From the model, the interface shear stress between the base and the reinforcement was determined when peak load was applied and is shown in Figure 5. This distribution can then be adjusted up or down according to Equations 1 and 8. The presence of a permanent interface shear stress implies that restraint against lateral motion is provided to the base, which grows with increasing traffic passes. This further implies that lateral stress confinement is created and grows with increasing traffic passes. Increased confinement provides for an initial stress state with a higher mean stress that is available for the next application of traffic load. The stress state with the higher confinement will produce a stiffer response of the aggregate, whose stiffness is mean stress dependent. This effect can be captured in response models using non-linear stress dependent models for the aggregate.

The stress state due to the permanent interface shear stress can be determined by creating a second

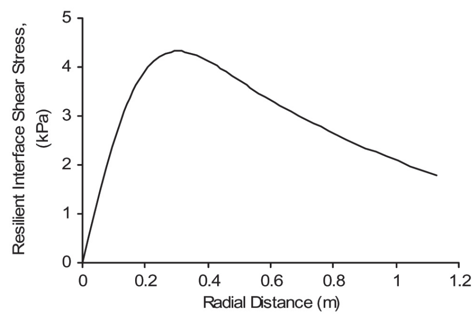

Figure 5. Interface shear stress distribution for an example problem.

finite element model of the pavement where the shear stress distribution is applied as equivalent nodal forces to the nodes having been in contact with the reinforcement and is necessarily performed on a model without reinforcement. The lateral stress for the elements along the model centerline are then extracted from the model and are taken as the stresses due to the presence of the permanent interface shear stress. These stresses, along with the vertical stresses due to material self-weight, are then used as the initial stress state for the base aggregate in a subsequent analysis of the reinforced pavement. This final analysis then provides response measures, such as tensile strain in the asphalt concrete and vertical strain in the pavement layers, that can then be used in damage models for determining relative damage over the series of traffic passes for which Equations 1 and 8 have been analyzed and used as input to the finite element models.

5 CONCLUSION

The use of field measurements of reinforcement strain in base-reinforced flexible pavements combined with a simple theoretical analysis of the reinforcement has been shown to be useful for predicting the interface shear stress between the reinforcement and the base aggregate. The relationship between the permanent to dynamic strain ratio and the number of normalized traffic passes is seen to depend on the reinforcement type and material direction. It is believed that this relationship is unique for a particular reinforcement-aggregate combination, however further work is needed to demonstrate this. A specific relationship for a particular reinforcement-aggregate combination may be related to the material's interaction properties, however further work is also needed to establish this relationship. The use of the permanent to resilient reinforcement strain ratio to determine the permanent interface shear stress for a given level of traffic passes requires the knowledge of the dynamic interface shear stress induced during a single traffic pass. This can be estimated from a finite element response model of the reinforced pavement. With this information, the influence of the permanent interface shear stress on confinement of the base aggregate can be determined using additional finite element models.

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