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A finite element study on optimum location of geogrid layer installation in asphalt overlay

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ABSTRACT: Reflective cracking is one of the more serious distresses associated with existing hot mix asphalt (HMA) or Portland concrete cement (PCC) pavements overlaid with an asphalt overlay. Preventive maintenance techniques have included incorporating geosynthetic materials, defined herein as grids, fabrics, or composites, into the pavement structure. These materials have exhibited varying degrees of success and their use within a particular agency has been based primarily on local experience or a willingness to try a product that appears to have merit. The key to obtaining optimum performance of a geosynthetics and related productions is correct installation. In this paper the effect of geogrid(GGR) installation depth on reflective cracking control has been considered using finite element method. A finite element analysis was carried out using ANSYS 6. Software in order to conduct comprehensive study on geogrid installation depth for preventing propagation the cracks into the overlay. Study was carried out for three location of geogrid installation in overlay; one third of overlay thickness, two third of overlay thickness, bottom of overlay. The effect of size variation of crack causing stresses and strains were considered in the above three locations. The result of study indicated decreasing of stresses causing crack propagation (i.e. tensile stresses) by using geogrids with higher elastic modulus. The optimum depth for geogrid installation in overlay was found to be at the bottom of overlay where the maximum tensile stresses exist.

1 INTRODUCTION

Many hot-mix asphalt (HMA) overlays prematurely exhibit a cracking pattern similar to that, which existed in the old, underlying pavement. The cracking in the new overlay surface is due to the inability of the overlay to withstand shear and tensile stresses created by movements concentrated around preexisting cracks in the underlying pavement. This movement may be due to traffic loading causing differential deflections at cracks in the underlying pavement layers, expansion or contraction of subgrade soils, expansion or contraction of the pavement itself due to changes in temperature, or combinations of these phenomena. Pavement movement, induced by any of the above causes, creates shear and/or tensile stresses in the new overlay. When these stresses become greater than the shear or tensile strength of the HMA, a crack develops in the new overlay. This propagation of an existing cracking pattern from the old pavement into and through a new overlay is known as reflective cracking. Increasing traffic loads, inclement weather, and lack of proper maintenance, only compounds this problem and inhibits the serviceable life of these pavements many cities, counties and state Departments of Transportation (DOT) (Cleveland et al. 2003). Preventive maintenance techniques to reduce the severity of reflective cracking have included incorporating geosynthetic materials, defined herein as grids, fabrics, or composites, into the overlay. Grids and composites are newer generation materials developed by manufacturers. Grids are typically composed of prestressed high-density polyethylene, glass fibers, polypropylene, or high modulus woven polyester. These products are designed to exhibit high modulus at low strain levels such that their reinforcing benefits begin before the protected pavement layer fails in tension (Cleveland et al. 2003). The geogrid layers has exhibited varying degrees of success and their use within a particular agency has been based primarily on local experience or a willingness to try a product that appears to have merit. The key to obtaining optimum performance of a geogrid and related productions is correct installation. In this paper the effect of geogrid installation depth in reflective cracking control has been considered with finite element method. A finite element analysis was carried out using ANSYS 6. Software in order to conduct comprehensive study on geogrid installation depth affects in reducing the severity or delaying the appearance of reflective cracking in HMA overlays. Study carried out for three location of geogrid installation in overlay; one third of overlay thickness, two third of overlay thickness, bottom of overlay. The changes of crack causing stresses and strains were considered in these three locations.

2 THEORETICAL METHODOLOGY

2.1 *Fatigue fracture*

Fatigue is the general phenomenon of material failure due to the growth of microscopic flaws as a result of repeated loading (Shackelford 1992). These microcracks become more visible as the stress concentrations at the crack tip increase and cause further crack propagation. Paris' Law (Paris and Erdogan 1963), as provided in Equation 1, defines the fundamental fracture law governing the rate of crack growth in a material based on linear elastic fracture mechanics:

$$\frac{dc}{dN} = A(\Delta K)^n \tag{1}$$

where C = crack length, N = number of load applications, $\frac{dc}{dN}$ = rate of crack growth, ΔK = change of stress intensity factor during loading and unloading and A, n = fracture parameters for the asphalt mixture. Equation 2 is specific form of the Equation 1 for asphalt overlay:

$$N_f = \int_0^h \frac{dc}{A\,[k(c)]^n} \approx \sum_{i=1}^{N} \frac{\Delta c}{A\,[k(c_i)]^n} \tag{2}$$

where: N_f = fatigue life of asphalt mixture, h = asphalt overlay thickness and, C_i = length of crack after load cycle i and Δc is proportion of $\frac{h}{N}$.

2.2 *Experimental relations*

The rule of geosynthetic in reinforcing overlay against fatigue is to reduce stresses and strains at a certain distance from tip of the crack so fatigue law is stated as follow (Vanelstraete, and Francken 1996):

$$\varepsilon_{ini} = KN^{-\alpha} \tag{3}$$

where: ε_{ini} = Initial tensile or shear strains causing fatigue, N = asphalt concrete fatigue life, K = factor depending on mixture composition and α = slope of the fatigue curve. Based on researches carried out by of BRRC, the parameter α is equal to 0.21 and factor K equal to 0.26 in order to estimate fatigue life of the asphalt mixture based on shear strains at 10 mm distance above the crack tip (Vanelstraete, and Francken 1996). So to determine the overlay fatigue life, Equation (4) can take the following form

$$N = \frac{4.856}{10^{14}}\,\varepsilon_{zx}^{-4.76} \tag{4}$$

where ε_{zx} = shear strains 10 mm above the existing crack.

3 FINITE ELEMENT MODEL

In order to analyze overlay reinforced with geogrid layers, F.E. package (ANSYS 6) was utilized. The plane strain two-dimensional finite element model represents cracked pavement layers and new reinforced overlay. Both linear and nonlinear behaviors of the pavement layers were considered in the analyses.

3.1 *Model geometry*

The length of model was selected based on trial and error, so that the stresses were negligible out of the mesh boundaries. The length of model is 2 m. The layers thicknesses are tabulated in Table 1.

Table 1. Thicknesses of pavement layers in the finite element model.

Layer	Thickness (mm)
Overlay	150
Geogrid	2.5
Cracked pavement	150
Base	150
Sub base	300
Subgrade	500

3.2 *Layers properties*

The layer properties are presented in Table 2. The Drucker–Prager criterion was used in order to analyze the nonlinear behavior of the base and subgrade. The geogrid behavior was also considered to be elasto perfectly plastic. The strain associated with plastic stress (σ_p) was selected to be between 5 to 7% for the geogrid.

Table 2. The properties of layers used in finite element study.

Layer	E (MPa)	v	γ	C	φ	σ_p
Overlay	3000	0.35	19			
Geogrid	10000	–	–			
Wearing course	2000	0.35	19			
Base	250	0.3	17.5			
Sub base	200	0.3	16.5			
Subgrade	50	0.35	15			
Geogrid						Variable
Base				5	40	
Subgrade				10	25	

[$\sigma_p(MPa)$, $C(kPa)$, $\gamma(KN/m^3)$]

The crack was modeled as a discontinuity in the wearing course elements. The crack width was assumed to be 5 mm. All layers were assumed to be fully bounded. The crack within the wearing course in FE model of pavement is shown in Fig. 1.

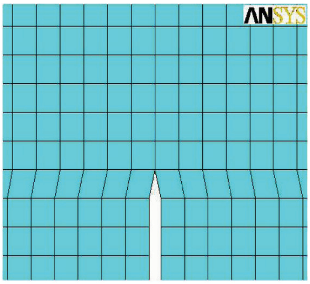

Figure 1. Finite element mesh in vicinity of old crack.

3.3 *Loading system*

As this study focuses on initial phase of crack propagation, traffic loading was considered. The pavement is subjected to vertical load of 0.7 MPa applied on circular loaded area with radius of 135 mm.

3.4 *Elements*

The pavement layers and the geogrid were modeled using two-dimensional plane strain solid element and cable element, respectively.

4 OPTIMUM LOCATION FOR GEOGRID INSTALLATION

F.E. study was carried out for three depths of geogrid installation in overlay: 1. one third of overlay thickness, 2. two third of overlay thickness, 3. bottom of overlay. Fig. 2 shows the pavement section and geogrid depths installation in overlay considered in the analysis. The changes of crack causing stresses and strains were considered in these three locations.

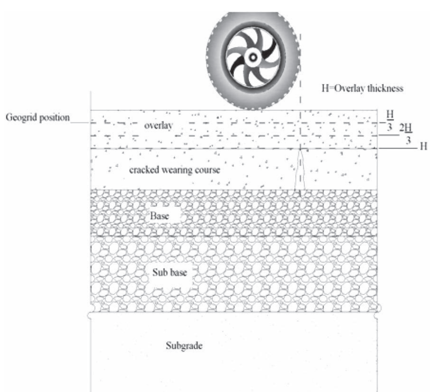

Figure 2. Pavement section and geogrid location in FE study.

4.1 *Tensile stress*

Figure 3 shows that the variation of tensile strain at the crack tip for different locations of geogrid. As can be seen from this figure, minimum tensile stress is obtained as the geogrid installed at the bottom of overlay. In this location, the tensile stress at crack tip decrease up to 30%. In the case of installation depths of 5 and 10 cm, these decreases are 3% and 6%, respectively.

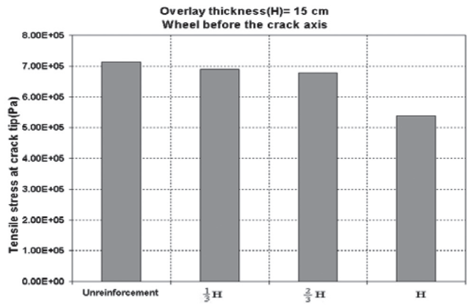

Figure 3. Tensile stress at crack tip versus different depths of geogrid installation in overlay.

4.2 *Shear stress*

According to Fig. 4 the variation of shear stress in vicinity of crack tip is independent of geogrid layer installation depths. As it can be seen for geogrid at various depths, shear stress decreases about 10% at crack tip.

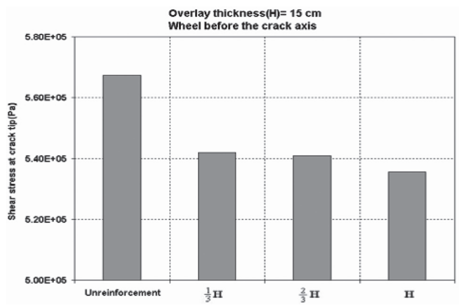

Figure 4. Shear stress at crack tip versus different depths of geogrid installation in overlay.

4.3 *Tensile strain*

Tensile strain is one of the most main factors of crack propagation. Based on results presented in Fig. 5 geogrid layer installation at the bottom of overlay reduces the concentrated tensile strain at the crack tip up to 30%. The effect of geogrid installation in other depths on tensile strain is not significant.

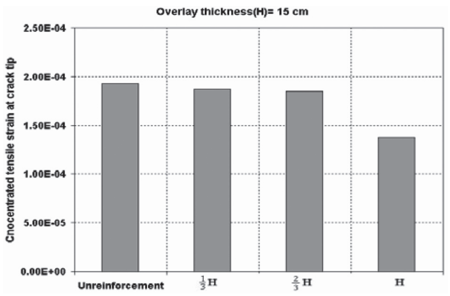

Figure 5. Concentrated tensile strain changes at the crack tip versus different depths of geogrid installation in overlay.

4.4 *Overlay fatigue life*

Equation 4 was used to estimate fatigue life of the asphalt overlay based on shear strain due to traffic loading at 10 mm distance above crack tip. Based on this equation and shear strain obtained from the analysis, geogrid at the bottom of overlay increases the overlay cracking life up to 2 time (Fig. 6).

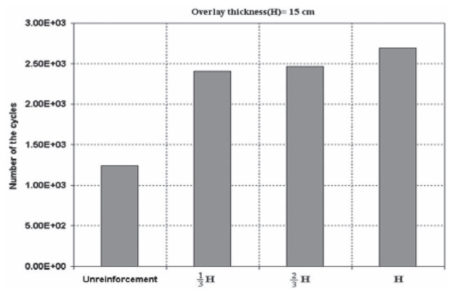

Figure 6. Number of cycle to crack initiation in overlay versus depths of geogrid installation in overlay.

5 CONCLUSION

In this research F.E. analysis was conducted on the best location of geogrid layers installation in order to decrease of crack propagation causing stresses (tension and shear). The result of study indicated decreasing of stresses causing crack propagation (i.e. tensile stresses) by using geogrids with higher elastic modulus.

The optimum depth for geogrid installation was obtained to be near of bottom of overlay where the maximum tensile stresses exist. Assuming that both shear and tensile stress influence the crack propagation, using a system capable of increasing the resistance of pavement against shear stress (in addition to geosynthetic layer) is necessary.

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