Backanalysis of Geosynthetic Reinforced Asphalt Pavements

M. A. Medeiros, Department of Civil and Environmental Engineering-FT, University of Brasilia, Brasilia, Brazil,
E.M. Palmeira, Department of Civil and Environmental Engineering-FT, University of Brasilia, Brasilia, Brazil,
F. Evangelista Junior, Department of Civil and Environmental Engineering-FT, University of Brasilia, Brasilia, Brazil,
J. R. Obando-Ante, Facultad de Ingeniería Civil, Universidad de Cauca, Cauca, Colombia

ABSTRACT
One of the most common applications of geosynthetics is in highways and railways; this type of material has been widely used in pavement structures over the past 30 years. They can be applied for: separation, stiffening, drainage, reinforcement, filtration, barrier etc. As reinforcement, these materials can be used to increase the number of loading cycles or reduce the thicknesses of asphalt layer, base or subbase, increase the stiffness of the subgrade, etc. Many experimental and numerical studies have been conducted aiming at evaluating the performance of geosynthetics as reinforcement of pavements. This study compares predictions from numerical analysis of geosynthetic reinforced asphalt pavements with results from large scale tests in the laboratory. Four types of geosynthetics were used in the investigation: a PET geogrid and geocomposite, and two PVA geocomposites. The numerical simulation was carried out using finite element software. The numerical analyses allowed to extend the results and conclusions obtained by the experimental study. The results obtained showed that the performance of geosynthetics as reinforcement increased the service life, ending the crack propagation in a low cycle fatigue based in fracture mechanics approach.

Key-words: geosynthetics, reinforcement, flexible pavements, numerical modelling.

RESUMO
Uma das aplicações mais comuns dos geossintéticos é em rodovias e ferrovias; esse tipo de material tem sido amplamente empregado em pavimentos nos últimos 30 anos. Eles podem ser aplicados com a finalidade de: separação, enrijecimento, drenagem, reforço, filtração, barreira, etc. Como reforço, esses materiais podem ser utilizados para aumentar o número de ciclos na vida útil ou reduzir a espessura de uma camada de asfalto, base ou sub-base, aumentando a rigidez do subleito, etc. Muitos estudos numéricos e experimentais têm sido realizados com o objetivo de avaliar o desempenho de geossintéticos como reforço em pavimentos. O presente estudo compara respostas de uma análise numérico de geossintéticos como reforço de pavimentos com resultados de ensaios em laboratório. Quatro tipos de geossintéticos foram usados na pesquisa: uma geogrelha e um geocomposto de PET e dois geocomposto em PVA. A simulação numérica foi realizada utilizando um programa comercial de elementos finitos. A análise numérica permitiu ampliar os resultados e conclusões obtidas experimentalmente. Os resultados mostraram que o desempenho dos geossintéticos como reforço aumentaram a vida útil de serviços, estabilizando a trinca para uma abordagem de fadiga de baixo ciclo em mecânica da fratura.

Palavras-chave: geossintéticos, reforço, pavimentos flexíveis, modelagem numérica.

1. INTRODUCTION

The pavement surface that presents excessive cracking represents a relatively expensive and continuous work to the responsible for roadways maintenance. Commonly, the cracked pavements are treated using a new overlay layer, whose thickness change between 25 and 100 mm (Koerner, 1989). An alternative to inhibit or delay the reflective cracking in asphalt overlays is the use of geosynthetics reinforcement.

One of the most severe problems associated with shortening pavement life is cracks. This phenomenon can occur due to low-frequency charging cycles, higher traffic, pavement oxidation and/or temperature variations (De Bondt, 1998). The cracks, besides representing a zone of pavement weakness, which modifies the stress distribution along with the upper layers, also act as a water inlet for the base and subbase layers and may lead to pumping — fines and degradation of these layers, mainly when composed of soils with lateritic behavior.

Roberts et al. (1996) define four main methods for reducing crack reflection. They include:

i. Increased HMA layer thickness;
ii. Special treatments on an existing surface;

iii. Treatments only in cracks and/or joints; and
iv. Special design considerations for the HMA layer (including geosynthetics reinforcement).

These reinforcements can be a mesh steel inclusion, glass fiber, polypropylene or polyethylene geogrid, geotextiles, etc., and works as a reinforcement element as well stiffening, also could function as stress decreasing zone at the crack tip (Zornberg, 2017; Koerner, 1989). The main aims of the use of these reinforcements are: decrease the overlay thickness for the same life service; or increase the life service using the same overlay thickness (Koerner, 1989).

The Fracture Mechanics, through the initial Griffith's (1921) and Irwin's (1957) studies, studies the crack behavior from three independent kinematics movements, from the crack tip, whose relative displacement mode near this tip contributes to the crack growth. These modes are presented in Fig. 1 and defined as:

a) Mode I (opening) – the main separation occurs in the normal direction from the normal plane of the fracture, trying to open it in two planes of separation, with symmetric displacements.
b) Modo II (in-plane shear) – occurs the in-plane shear along the same loading direction with antisymmetric displacements.
c) Modo III (out-of-plane shear) – occurs the in-plane shear along the normal loading direction with antisymmetric displacements.

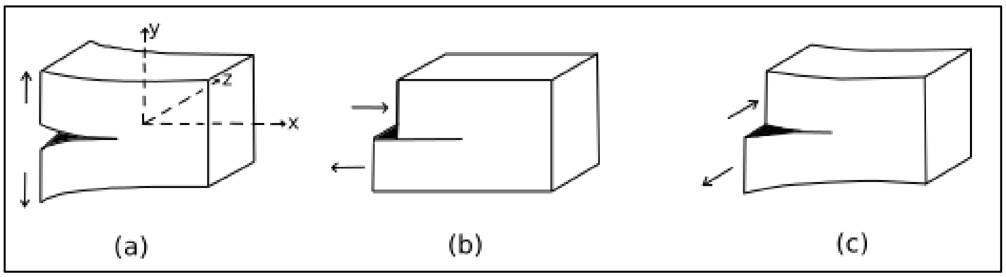

Figure 1. Crack modes of movements: (a) Mode I – opening; (b) Mode II – in-plane shear; (c) Mode III – out-of-plane shear

The cracking mechanisms of the mode I are most common in pavement loads. These mechanisms are due to traffic and temperature changing (dilatation and contraction of the overlay). Also, the inducted loading due to the traffic can generate mode II. However, mode III can occur in rigid pavements due to the longitudinal deformation of the concrete plates but rarely is found in asphalt overlays.The three modes are sufficient to describe the crack movement (Rodrigues, 1991).

The fatigue crack growth in pavements can be model using the modified Paris' Law (Paris; Erdogen, 1963), considering the stable stage of crack propagation (Eq. 1):

$$\frac{da}{dN} = A \cdot K^n \quad [1]$$

where:

a = crack length;
N = number of loading cycles
K = Stress Intensity Factor
A, n = material constants
da/dN = crack growth rate

The Traffic Benefit Ratio (TBR) represents the service life gain, in terms of load repetition cycles, for a reinforced pavement relative to unreinforced pavement, expressed as in Eq. 2:

$$TBR = \frac{N_R}{N_{UR}} \quad [2]$$

where:

TBR = the traffic benefit ratio;

N_R = the number of load cycles required for crack reflection in the case of geosynthetic reinforcement; and
N_{UR} = the number of load cycles required for crack reflection in the case without reinforcement.

Fei & Yang (2008) analyzed the performance of geogrid reinforced asphalt pavements using the finite element method. In the study, numerical analyses were performed to calculate the stress in the pavement with and without reinforcement, as well as under different interaction conditions between geogrid and pavement. The results demonstrate that the ideal position varies with the different pathology prevention requirements, with useful improvement in the stress conditions in the crack region with the presence of the geogrid.

Several experimental and numerical modeling studies have been carried out to verify the performance of geosynthetics as a system against crack reflection in flexible pavements. The researchers found that in all cases the pavement life was increased compared to the unreinforced situation (Alexander, 1996; Jaecklin & Scherer, 1996; Bühler, 2007; Khodaii et al., 2009; Barraza et al., 2011; Obando-Ante & Palmeira, 2015; Fallah & Kodhaii, 2015; Noory et al., 2017; Sireesh-Saride & Vinay-Kumar, 2017).

2. BACKANALYSIS AND NUMERICAL MODELLING

2.1 Problem Description

The problem is the growth analysis of a crack (bottom-up) from a two-dimensional model composed of an asphalt concrete beam supported by a Neoprene compressible layer, which rests on a surface considered slightly displaceable in the vertical direction. The beam has an initial notch, with 16 mm high and 4 mm wide, positioned in the lower center of the component. Two conditions were considered: one unreinforced condition and one reinforced with geosynthetic material positioned in the center of the beam (50 mm from the base). The numerical simulation was carried out on ABAQUS®.

2.2 Constitutive Models and Material Properties

For the numerical simulation, it was considered an elastic linear model for the asphalt concrete behavior, whose characteristics considered were: dynamic modulus E * = 6,060 MPa and Poisson's ratio v = 0.35 defined by Obando (2016) for the condition of charging frequency equal to 1 Hz.

In addition to the elastic-linear model, damage initiation and surface interaction are included, which are suitable for crack growth analysis. In the numerical simulation, it was adopted the maximum stress model, whose value specified for asphalt concrete was 1.15 MPa.

For the neoprene support, the same model was matched, whose material properties is: Young's modulus E = 21 MPa and Poisson's ratio v = 0.35 (Obando-Ante & Palmeira, 2015). The material properties of geosynthetics reinforcement are detailed in Table 1.

Table 1. Reinforcement material properties

Characteristics	G1	G2	G3	G4
Type of Geosynthetic	GCO	GCO	GG	GCO
Material	PET	PVA	PET	PVA
Grammage (g/m²)	280	520	250	230
Thickness (mm)	1.70	2.45	1.30	1.60
T_{max} (kN/m)	38	62	55	64
J_{sec} (kN/m)	500(1)	690(1)	789(1)	937(1)
ε_{max} (%)	9.1	11.7	7.6	12.1
σ_{max} (MPa)	12.67	20.67	18.33	21.33
E (MPa)	1,470	1,408	3,035	2,928

Note: J_{sec} secant stiffness measured for 5% strain, T_{max} = maximum tensile force; ε_{max} = maximum stress; σ_{max} = maximum stress; E = Young's Modulus; GCO = geocomposite; GG = geogrid.

2.3 Loads and Boundary Conditions

The model consists of an asphalt concrete beam supported by a neoprene layer (compressible) that is restricted in the horizontal axis in 1 point and vertical restricted in the whole bottom surface. The load magnitude is 560 kPa, with a frequency of 1 Hz. In Figure 2 can be seen the loads and boundary conditions of the problem.

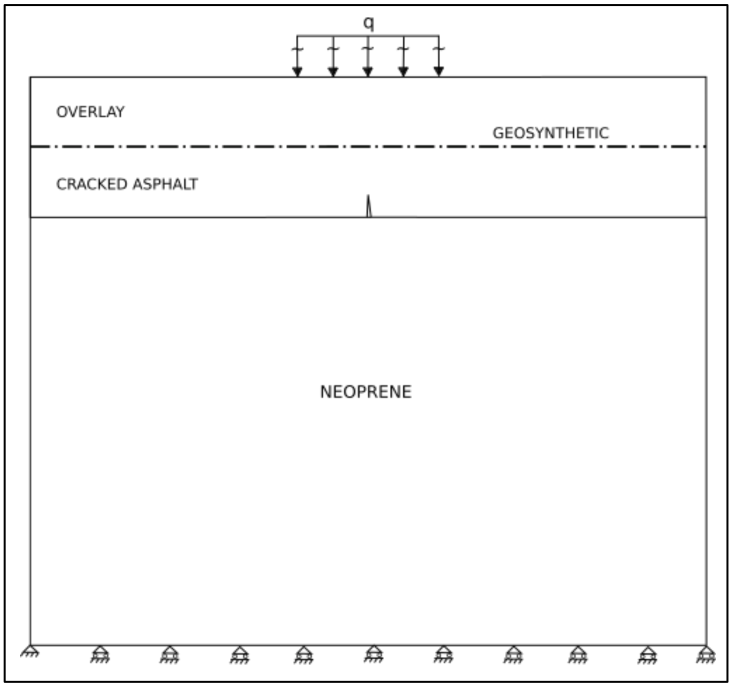

Figure 2. Load and boundary conditions in the numerical model.

2.4 Mesh Generation

The numerical simulation was carried out in an FE software using quadratic elements for plane stress condition and beam elements for the geosynthetics reinforcement. According to Vethe (2011), for better accuracy of the results, the elements of mesh in the crack region need to have a size of about 3% of the crack length.

2.5 Steps of loading

There are three steps of loading conditions:

i) Initial conditions: crack initial size and boundary conditions;
ii) Static step: an initial and static load which propagates the damage for one finite element before the cyclic; and
iii) Direct cyclic step: application of cyclic load until the failure or stabilization of the damage. The constitutive properties cannot be changed in this step.

3. RESULTS AND DISCUSSION

3.1 Crack Reflection

The Paris constants obtained for unreinforced asphalt using backanalysis were: $A = 1.6 \times 10^{-8}$ mm/cycle.(MPa√m)$^{n/2}$ and n = 3.75, whose values are according with default values (Elseifi & Al-Qadi, 2004;). The constants for reinforced asphalt cannot be found due to the reflection was partial. In Fig. 3 are showed the predicted life service using XFEM and LCF approach for reinforced asphalt. In Fig. 3 are presented the predicted life service for unreinforced (SR) situation and for each geosynthetic-reinforced beam (G1, G2, G3 and G4) investigated.

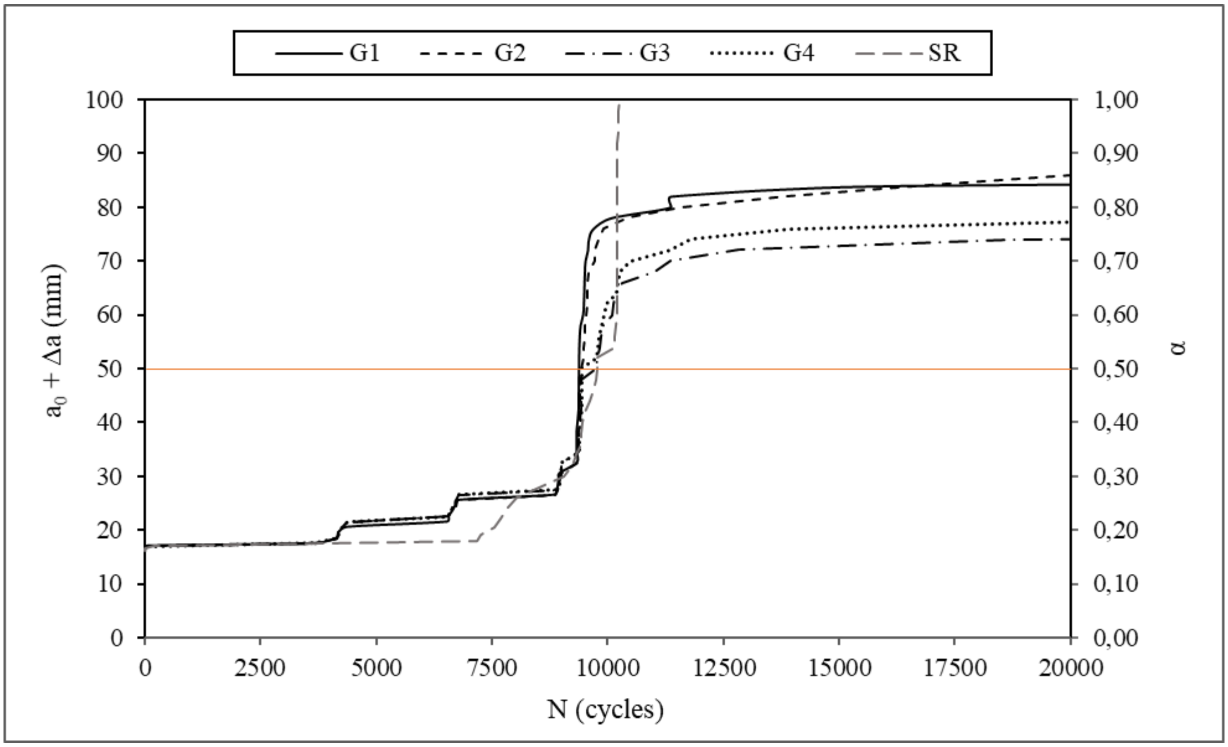

Figure 3. Predicted life service for unreinforced and reinforced pavement

All of the geosynthetics reinforcements stabilized the crack propagation, which can be inferred that tensile-stress intensity at the crack tip may is less than sufficient to continue propagating the damage. The compressive-stress stabilize the crack, stopping its opening, which can be the most significant benefit of the geosynthetic reinforcement. The geosynthetic G1 and G2 presented a crack length for asymptotic behavior bigger than other geosynthetics (G1 and G2 around 86 mm and others around 78 mm).

3.2 Traffic Benefit Ratio (TBR)

The TBR was calculated considering a crack length of 70 mm (approximated best value for geosynthetic-reinforced pavement) and are presented in Fig. 4. The reinforcement G4 showed the better TBR for numerical modelling, that is expected due its higher stiffness. However, G2, although its stiffness smaller than G3, presented a TBR bigger than it which means its thickness could increase the predicted service life.

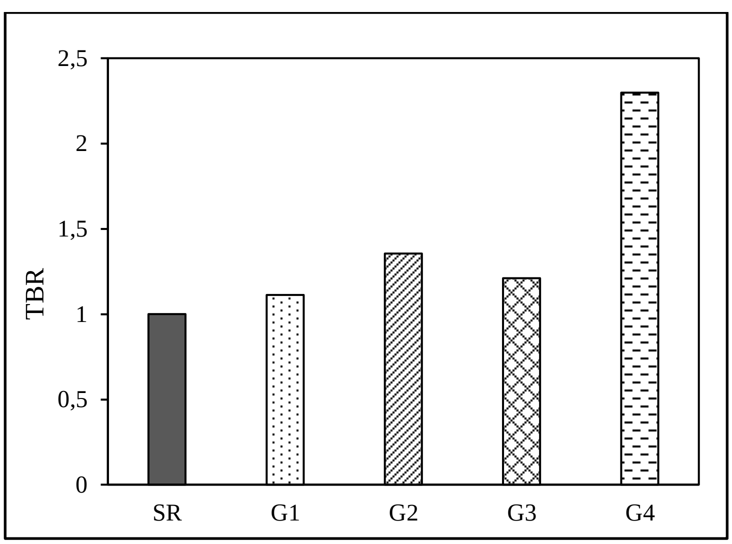

Figure 4. TBR on numerical model for 85 mm of crack length

4. CONCLUSIONS

In the numerical model, the geosynthetic reinforcement stabilizes the crack, preventing its reflection until the overlay surface. An analysis based only on TBR is not sufficient to understand the behavior and performance improvement of a geosynthetic-reinforced asphalt overlay. The differences between numerical modeling and laboratory tests can be related to the changes in damage criterion in reinforced asphalt. These changes need to be investigated for conclusive results about the benefit generated by geosynthetics in asphalt concrete.

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REFERENCES

Alexander, W. S. (1996). Geogrid reinforcement of asphalt overlays on Australian airport pavements. In: *Reflective Cracking in Pavements* : Design and performance of overlay systems, eds.: Francken, L., Beuving, E., Molenaar, A. A. A., 3.ed., Londres : E & FN SPON, 260-267.

Barraza, D. Z., Pérez, M. A. C., Fresno, D. C., Zamanillo, A. V. (2011). Evaluation of anti-reflective cracking systems using geosynthetics in the interlayer zone. *Geotextiles and Geomembranes*, 29: 130-136.

Bühler, A. (2007). *Estudo do Efeito de Grelhas de Reforço na Restauração de Pavimentos*. Tese – Doutorado em Engenharia Aeronáutica e Mecânica, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, 322p.

Elseifi, M. A. & Al-Qadi, I. L. (2004). A Simplified Overlay Design Model against Reflective Cracking Utilizing Service Life Prediction. *Road Materials and Pavement Design*, 5(2): 169-191

Fallah, S. and Khodaii, A. (2015). Evaluation of parameters affecting reflection cracking in geogrid-reinforced overlay. *J. Cent. South Univ*., 22: 1016−1025.

Fei, Y. Y. & Yang, Y. H. (2008). FEM Analysis on geogrid reinforced asphalt concrete pavement. In: *4th Asian Regional Conference on Geosynthetics*, June 17-20, 2008, Xangai, China: 677-682.

Jaecklin, F. P. & Scherer, J. (1996). Asphalt reinforcing using glass fibre grid "Glasphalt". In: *Reflective Cracking in Pavements* : Design and performance of overlay systems, eds.: Francken, L., Beuving, E., Molenaar, A. A. A., 3.ed., Londres : E & FN SPON, 268-277.

Khodaii, A., Fallah, S., Nejad, F. M. (2009). Effects of geosynthetics on reduction of reflection crack in asphalt overlays. *Geotextiles and Geomembranes*, 27: 1-8.

Koerner, R. M. (1989). *Designing with geosynthetics*. 4.ed. New Jersey : Prentice-Hall. 761p.

Noory, A., Modhadas-Nejad., F., Khodaii, A. (2017). Evaluation of shear bonding and reflective crack propagation in a geocomposite reinforced overlay. *Geosynthetics International*, 24 (4): 343-361.

Obando, J. R. A (2016). *Desempenho de misturas asfálticas reforçadas com geossintéticos*. Tese de Doutorado, Publicação G.TD-128/16, Departamento de Engenharia Civil e Ambiental, Universidade de Brasília, Brasília, DF, 175 p.

Obando-Ante, J. & Palmeira, E. M. (2015). A Laboratory Study on the Performance of Geosynthetic Reinforced Asphalt Overlays. *Int. J. of Geosynth. and Ground Eng*., 1: 1-5.

Paris, P. C. & Erdogan, F. (1963). A Critical Analysis of Crack Propagation Laws. *Journal of Basic Engineering*, 85: 528-533.

Roberts, F. L., Kandhal, P. S., Brown, E. R., Lee, D. Y., Kennedy, T. W. (1996). "*Hot Mix Asphalt Materials, Mixture Design, and Construction*." Lanham, Maryland: NAPA Education Foundation, 603p.

Rodrigues, R. M. (1991). *Estudo do Trincamento dos Pavimentos*. DSc. Thesis (Doctor of Science in Civil Engineering) – COPPE, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, 208p.

Sireesh-Saride & Vinay-Kumar, V. (2017). Influence of geosynthetic-interlayers on the performance of asphalt overlays on pre-cracked pavements. *Geotextiles and Geomembranes*, 45: 184-196.

Vethe, Stine. *Numerical simulation of fatigue crack growth*. (2012). MSc thesis. Institutt for produktutvikling og materialer, 2012.

Zornberg, J. G. (2017). Functions and applications of geosynthetics in roadways. *Procedia Engineering*, 189: 298-306.