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Rutting Prediction of a Reinforced Cold Bituminous Emulsion Mixture using Finite Element Modelling

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Abstract

A three-dimensional (3D) finite element (FE) model of a reinforced cold bituminous emulsion mixture (CBEM) was built in order to investigate the effect of static wheel load on rutting formation and flexible pavement response. This model was developed to represent a four-layer pavement structure with elastic responses and to simulate the mechanical behaviour and pavement performance under static load condition. Also, it is focused on the prediction of the contribution of glass fibre (as a reinforcement material) in the surface course to the development of the tensile and shear strength of flexible pavements. The preparation and validation of the model were carried out in the pavement laboratory using experimental data. In this research, finite element analyses have been conducted using ABAQUS software, in which model dimensions, element types and meshing strategies are employed to achieve the desired degree of accuracy and convergence of the developed model. In addition, this developed model has been applied to CBEMs to investigate the effects of glass fibre on the performance of a reinforced pavement surface layer, as well as to study the effects of this fibre in terms of minimizing the vertical surface deflection, and horizontal and vertical displacements for the various courses. Finally, the FE model is capable of predicting surface damage to flexible pavements and their partial recovery following the application of the load. The results demonstrate the capability of the model to simulate the effect of fibre on vertical surface deflection (rutting), horizontal and vertical displacements in CBEM.

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Keywords: ABAQUS; cold bitumen emulsion mixtures; rutting; three-dimensional finite element.

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1. Introduction

Permanent deformation (rutting) is one of the most important and widespread types of damage encountered in flexible pavements, especially in countries that have high temperatures during the summer season. In all flexible pavement layers, the accumulation of permanent deformation under the effect of traffic loading causes rutting. Rut depth and width are mainly affected by the structural properties of the pavement layers, such as the layers' thickness, material quality, traffic loads and temperature [1]. The ability to predict rutting or permanent deformation in flexible pavements is an essential aspect of pavement design. Therefore, several simplification hypotheses are often applied in the analysis and design processes, such as the elastic behaviour and isotropic nature of pavement material. The basic hypotheses of the multi-layer pavement system include [2]:

- Flexible pavement layers are homogeneous and isotropic.
- Materials behaviour is elastic and linear.
- Materials are massless.
- Layer thickness is limited.
- Load is uniformly distributed over a rectangular contact area.

Boundary conditions were considered so that the contact between two layers is identical in terms of shear tension, vertical tension, vertical and radial displacements.

Several diagrams and tables have determined the stress, strain and displacement in the multi-layer system after proposing these equations [3]. Finite element analysis is a numerical method for solving these equations.

The research objective is to develop a finite element model for an existing flexible pavement that is capable of predicting the stress and strain responses of elastic pavements. The output of the model is the prediction of permanent deformation (rutting).

2. Classical rutting prediction approach

Classic attempts to model rutting analysis have concentrated on protecting the under layers. At the top of the subgrade layer, the vertical stress and strain are limited to controlling the permanent deformation of the whole pavement structure and also restricting the tensile stress and strain at the bottom of the lowest bituminous layer to control fatigue cracks [4]. A classic model of rutting prediction utilised in road pavement analysis is given in [4] :

$$N_f = 1.077 \times 10^{18} \left(10^{-6} \div \varepsilon_v\right)^{4.4843} \quad (1)$$

Where:
Nf : applied load (kN).
εv : vertical compressive strain at the top of subgrade layer.

Nowadays, comprehensive researches have been carried out using different laboratory test methods, such as the wheel tracking test, creep test, complex (dynamic) modulus test and triaxial test, combined with contributions from investigations into pavement field rutting [4]. It was noticed that rutting failure did not solely occur in the subgrade layer or other under layers but can also be a result of bituminous mixture problems. Consequently, it has become obvious that, in an accurate road pavement design procedure, cumulative permanent deformation in all pavement layers must be considered.

Three model types have been used to compute the permanent deformation in flexible pavements: empirical, mechanistic empirical and fully mechanistic. The empirical model is the simplest mathematical form fitted to controlled field data, depending on the regression equations. The properties of the materials and site conditions are not included in this type of modelling, whilst specific applications, for instance performance predictions in the road