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Modeling of cold mix asphalt evolutive behaviour based on nonlinear viscoelastic spectral decomposition

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HIGHLIGHTS

- Develop an evolutive constitutive model for cold mixes treated with bitumen emulsion.
- Develop an oedometric test to study the cold mix asphalt evolutive behaviour.
- Spectral merging between nonlinear elasticity and viscoelasticity.

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ABSTRACT

Given a political context in which energy and environmental stakes have become increasingly dominant, road engineering practices have favoured saving energy and protecting the environment. Among these practices, the use of cold mixes treated with bitumen emulsion has proven to be a suitable technique. Cold mix design, as well as the design of pavements including cold mix asphalt (CMA) layers, is highly empirical and based on local skills and tend to limit the development of this environmentally-friendly pavement technique. In the case of CMA, no mechanical behaviour law has been established to take into account its evolutive behaviour.

The paper is set in three parts. The CMA model is presented in Part I. The second part of the paper illustrates the numerical response of the model on a compressive sinusoidal load. The last part presents some first simulations of the cyclic oedometer laboratory tests. By comparing then to the numerical simulations, they show the relevance of the model to account for the CMA behaviour.

1. Introduction

Given a political context in which energy and environmental stakes have become predominant, road engineering practices have favored saving energy and protecting the environment [1]. Among these practices, the use of cold mixes treated with bitumen emulsion has proven to be a suitable technique. The design of pavements including cold mix asphalt (CMA) layers [2] however remains highly empirical and based on local skills. From prior experience, the transposition of established local rules from one site to another and their application to pavements subjected to medium or heavy traffic are not simple steps and tend to limit the development of this environmentally-friendly pavement technique. With this objective in mind, a French project with partners from industry and academia was launched a few years ago to promote the use of sustainable road techniques, among which CMA, through defining a rational and coherent CMA pavement design method and finding ways to expand its scope to higher traffic volumes than those typically encountered by this type of material.

CMA displays an evolutive behaviour [3,4,5], due to the use of a bitumen emulsion (i.e. mixture of water and bitumen) as binder. In the laboratory, the breaking of the bitumen emulsion and water release are both observed under gyratory compaction [6]. These phenomena are found to be highly correlated with the emulsion formulation, which must be adapted to the choice of aggregate. In pavements, after compaction the CMA continues to evolve according of the remained water content in the material, in

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exhibiting a behaviour that remains poorly understood [7]. In the fresh state, CMA behaves like soft and quasi-unbound granular materials. Over time, the material becomes increasingly stiffer with a mechanical behaviour resembling that of a bound asphalt concrete material. The time required to achieve this stiffer mechanical state is called “curing time”.

The objective of this paper is to develop a generic curing model for CMA, derived from “merging” the Boyce nonlinear elastic (NLE) model [8], which reflects the behaviour of unbound granular materials at a very early age, with the Huet model [9], which reflects the thermo-viscoelastic behaviour (VE) of hot mix asphalt (HMA) by means of a “curing function”. The obtained nonlinear viscoelastic model (NLVE) is based on the use of spectral decomposition for both NLE and VE components. The paper is set in three parts. The CMA model is presented in Part I. The second one of the paper illustrates the numerical response of the model on a compressive sinusoidal load. The last part presents some first simulations of the cyclic oedometer laboratory tests undertaken in parallel to this modelling work.

2. Development of a model to account of the NLVE and curing behaviour of CMA

To design a pavement structure, the first step consists of computing the strain and stress fields generated by the action of traffic loads. Those ones must then be compared with the long-term performances of materials under cyclic mechanical loadings (fatigue tests, cracking tests ...) and climatic conditions in relation with the specified pavement life.

The CMA model proposed herein is related to the first step.

2.1. Two generic models to describe the behaviour of the CMA in fresh and cured states

Our objective is to develop a generic curing model of CMA, whose behaviour varies from an unbound granular material at a very early age to the thermo-viscoelasticity of asphalt mixes over the long term. To fulfil this objective, two well-known models are firstly considered. One is the Boyce nonlinear elastic (NLE) model for characterising unbound granular materials, while the second is the Huet viscoelastic (VE) model known for its accurate description of HMA.

2.1.1. Boyce model (3D)

The Boyce’s model is a nonlinear extension of Hooke’s Law and is based on the hardening dependence with stress of the compressibility K_B and shear G_B moduli, which is typical of the reversible behaviour of unbound granular materials [8]. Using the standard signs and notations of continuum mechanics (contraction strain < 0, compressive stress < 0), the model is written in 3D:

$$\varepsilon_{vol} = -\frac{p}{K_B} \tag{1}$$

$$\varepsilon_q = \frac{q}{3G_B} \tag{2}$$

$$\text{with}: K_B = K_a \frac{\left(\frac{p}{Pa}\right)^{1-n}}{1-\gamma\left(\frac{q}{p}\right)^2} \tag{3}$$

$$\text{and}: G_B = G_a \left(\frac{p}{Pa}\right)^{1-n} \tag{4}$$

where:

- $p = -\frac{1}{3}tr(\sigma)$: is the mean pressure;
- $q = \sqrt{\frac{3}{2}tr(s^2)}$: is the deviatoric stress with $s = \sigma + -\frac{1}{3}tr(\sigma)I$ (σ, s = stress and deviatoric stress tensors, I = unit 3x3 tensor);$\varepsilon_{vol} = tr(\varepsilon)$: is the volumetric strain;
- $\varepsilon_q = \sqrt{\frac{2}{3}tr(e^2)}$: is the deviatoric strain with $e = \varepsilon - \frac{1}{3}tr(\varepsilon)I$ (ε, e = strain and deviatoric strain tensors);
- P_a, K_a, G_a, γ are positive parameters;
- n is an exponent lying between 0 and 1.

As an example, Figs. 1 and 2 show the modelling of a cyclic oedometric triaxial test with Boyce model.

2.1.2. Huet model (1D)

The thermo-viscoelastic model as defined by Huet is composed of a series of elements: one spring E_∞ and two parabolic dashpots (h and k) (Fig. 3).

The complex modulus ($E^*_H(\omega)$) and creep function ($F_H(t)$) of the Huet model are expressed as:

$$E^*_H(\omega) = \frac{E_\infty}{1 + \delta(i\omega a(\theta))^{-k} + (i\omega a(\theta))^{-h}} \tag{5}$$

$$F_H(t) = \frac{1}{E_\infty}\left(1 + \frac{\delta}{\Gamma(k+1)}\left(\frac{t}{a(\theta)}\right)^k + \frac{1}{\Gamma(h+1)}\left(\frac{t}{a(\theta)}\right)^h\right)H(t) \tag{6}$$

where E_∞ is the elastic modulus, h, k are the exponents of parabolic dashpots lying between 0 and 1, δ is the weight of dashpot (k) (positive value), Γ is the Euler function, $a(\theta)$ is the function whose time dimension accounts for the dependence of the material behaviour on temperature θ (decreasing exponential type). $H(t)$ is the Heavyside function.

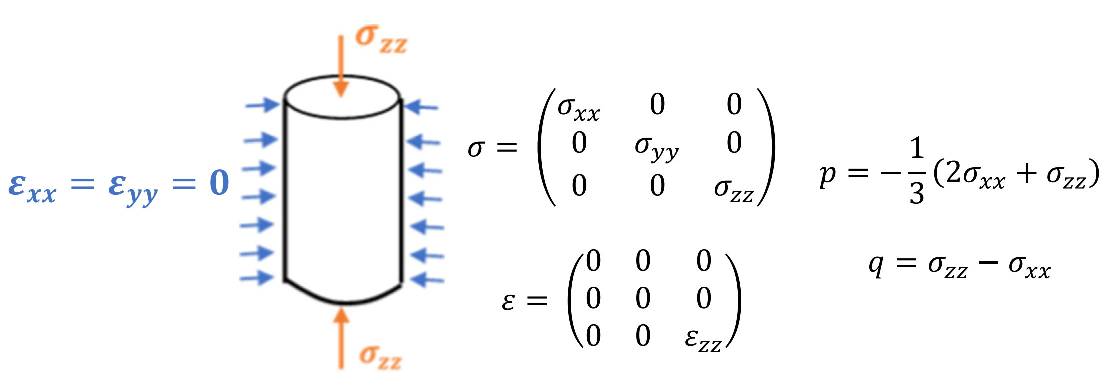

Fig. 1. Illustration an oedometric triaxial test.