8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

A CONSTITUTIVE MODEL FOR ELASTO-VISCOPLASTIC BEHAVIOUR OF PAVEMENT MATERIALS

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Key Words: *Asphaltic materials, Bounding surface theory, Consistent viscoplasticity, Elastic-viscoplastic, Rate dependency*

ABSTRACT

The most commonly used pavement design procedures significantly lag behind contemporary design practices of other engineering materials such as soils, concrete, metals, etc. Most of the current pavement design practices are predominantly empirical procedures that are based on simplistic assumption of material behaviour. However, the research on the constitutive behaviour of pavement materials has shown that their deformation behaviour is dependent on the state of stress, temperature and strain rate [1]. Attempts to capture the constitutive behaviour of pavement materials, depending on the level of complexity, vary from linear elastic models, to viscoelastic and viscoplastic models. Recent developments in pavement design practice use a mechanistic approach based on elastic analysis of a layered pavement system [2],[3]. However, elastic analysis can not fully describe the complex response of pavement materials to the applied loads and environmental conditions.The objective of this paper is to develop a rigorous computational model to describe the elasto-viscoplastic characteristics of pavement materials with a particular emphasis on the rate dependent behaviour of asphalt-aggregate mixes.

An elasto-viscoplastic constitutive model is developed to capture the essential characteristics of bound and unbound pavement materials. Crucial to the formulation of the proposed model is dependence of the deformation behaviour of pavement materials on the state of stress and strain rate. In the model proposed, the elastic behaviour is captured through a non-linear model which uses a density and state of stress dependent bulk modulus. The viscoplastic strains are captured using the consistent viscoplasticity framework [4] and a rate-dependent yield function. The elasto-viscoplastic model also incorporates critical state theory to define failure and the bounding surface plasticity to capture development of viscoplastic strains under cyclic loading. The bounding surface formulation of Khalili et al [5] is extended to pavement materials by defining the evolution of the bounding surface as a function of temperature and strain rate in addition to the plastic volumetric strain. Additionally, the model uses a simple viscoplastic potential function to determine the direction of viscoplastic strains.

The model parameters are identified and their determination from standard laboratory tests is discussed.

Numerical implementation of the constitutive model involves integration of the elasto-viscoplastic constitutive equations and formulation of a finite element program. Integration of the constitutive equations is performed using Euler’s forward scheme. This scheme is a first order explicit algorithm in which the stresses are computed directly using the consistency condition, plastic potential and hardening rule at previously known stress points. The finite element equations are formulated by discretizing the equilibrium equations using Galerkin’s procedure. Capability of the model to reproduce the experimentally observed response of pavement materials is demonstrated using numerical simulations of a number of laboratory tests for a variety of loading conditions. Simulation results have been obtained for constant strain rate uniaxial extension tests, a static creep test and a repeated loading test. In all the tests considered, the model simulations matched the experimental data very well.

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