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Characterisation of Permanent Deformation of Silty Sand Subgrades from Multistage RLT Tests

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Abstract
In thin flexible pavements, unbound aggregate layers and subgrade, contribute largely to the rut formation of the pavement system. Therefore, realistic prediction of surface rutting requires models that can reliably capture the cumulative plastic deformation of pavement unbound materials under repeated loads. Here four models were evaluated to capture the accumulation of permanent deformation of two fine grained subgrade materials. The models were modified based on the time hardening concept allowing them to be used in a multistage repeated load triaxial (RLT) test procedure, in which a single specimen is exposed to a series of consecutive stress paths of varying magnitudes. The RLT tests were conducted on two non-plastic silty sand subgrade soils with different fines content and at four different moisture contents. The used triaxial testing system was capable of controlling the pore-air and pore-water pressures of the specimen and therefore the permanent deformation tests were carried out with controlled matric suction of the soil samples throughout the test. An effective stress approach was therefore used in the modelling. Using the test data, the model parameters were determined using a parameter optimisation algorithm and the qualities of fits achieved was analysed and compared through goodness-of-fit statistics. In general, the four permanent deformation models were found to work satisfactorily in capturing the accumulation of the permanent deformation of the tested subgrade materials. It was concluded that the multistage RLT test procedure has the potentials to be used for characterizing the permanent deformation behaviour of subgrade soils. This can considerably reduce the effort and time required for permanent deformation characterization of subgrade materials.

Keywords: Permanent deformation, moisture content, subgrade, unsaturated soil, suction, modelling, triaxial test.

1 Introduction

Rutting is one of the main modes of deterioration in pavements which is often associated with accumulation of plastic deformation in different pavement layers under repeated traffic loads. In thin pavement structures, unbound layers and subgrade significantly contribute to the load bearing capacity of the system and calculating surface rut requires calculation and summation of the permanent

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deformation of each individual layer using an appropriate permanent deformation model and material properties.

Pavement unbound materials generally exhibit an elastoplastic behaviour under repeated cyclic loads which are usually small compared to the strength of the material (Lekarp, 1999). The deformation of the material under these loading conditions consists of two parts: the recoverable (resilient) strain and the plastic (permanent) strain. Resilient and permanent deformation characterization of pavement materials are generally done through laboratory-based repeated load triaxial (RLT) studies in which loading and environmental conditions that are often experienced by the material in the field are simulated. The data obtained from these studies are then used to develop models that can predict the mechanical behaviour of the materials. (Hornych and El Abd, 2004; Lekarp et al., 2000, Li and Selig, 1996).

From a micromechanical perspective, the development of permanent strains under repeated cyclic loading can be described using the shakedown concept (Sharp and Brooker, 1984; Werkmeister et al. 2001) and can be classified into three different categories (Figure 1): the plastic shakedown (Range A), the intermediate response or plastic creep (Range B) and the intermediate collapse (Range C). The criteria for defining the shakedown concept ranges from RLT tests is described in Figure 1 (Werkmeister et al., 2004).

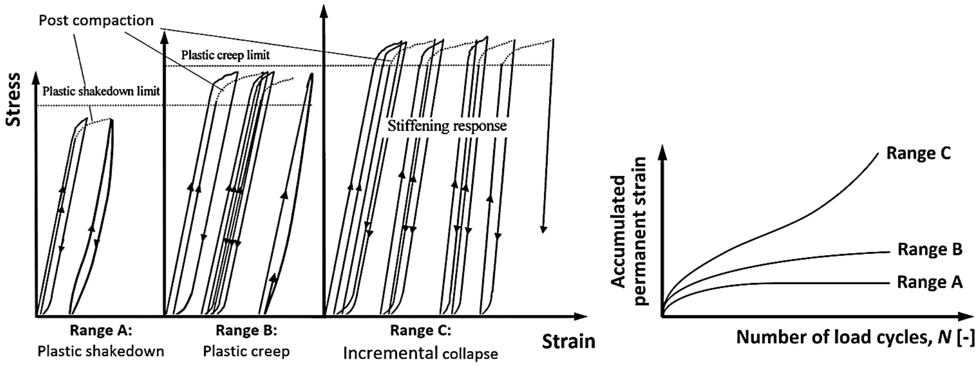

Figure 1: Theoretical behaviour of unbound materials under repeated cyclic load (left); different categories of permanent deformation development (right).

In permanent deformation characterization of unbound pavement materials usually a single stress path is used (single stage RLT test) where the specimen is subjected to a large number of load pulses with constant-amplitude and under constant confinement pressure. On the other hand and in the field, the material generally undergoes stress paths of different magnitudes. Therefore, characterization of material under different stress conditions requires preparation and testing of several specimen that is tedious and costly. To overcome this, so-called multistage RLT testing was introduced in which a single specimen is exposed to a series of consecutive stress paths of varying magnitudes.

Most of the permanent deformation models are developed and calibrated based on single-stage RLT tests and modelling the accumulated permanent deformation tests from multistage RLT tests has been a challenge. Erlingsson and Rahman (2013) formulated a general approach based on the time-hardening concept to mathematically estimate the accumulated permanent deformation of unbound granular materials from multistage RLT tests.

The objective of this paper was to study the feasibility of using the multistage RLT tests for unsaturated fine grained subgrades and modelling their permanent deformation accumulation using four different models that were originally developed for single stage RLT test procedures. For this purpose two silty sand subgrade soils were tested at different moisture conditions typically observed in field (Salour et al., 2015). The effective stress approach was used (Equation 1) in which the effect of soil suction was taken into account when calculating the material stress state (Nuth and Laloui, 2008).

$$\sigma' = \sigma_{net} + S\psi_m \quad [1]$$