AN ELASTOPLASTIC MODEL FOR PREDICTION OF PERMANENT DEFORMATIONS OF UNBOUND GRANULAR PAVEMENT LAYERS

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Summary This paper presents a simplified method for modelling of permanent deformations in order to estimate the rutting of low traffic flexible pavements. The method is based on an elastoplastic model of prediction of permanent deformations recently developed and consists in integrating the permanent strains along the vertical direction in order to obtain the vertical displacements in the structure (i.e. rutting of the layer).

CONTEXT

Rutting is one of the main causes of damage in low traffic flexible pavements and recent studies, dealing with the improvement of design methods for flexible pavements, have pointed out the key role of permanent deformations in the unbound granular layers. In spite of this, adequate methods for predicting permanent deformations in unbound pavement material are lacking.

The objective of this study is the prediction of the rutting of several experimental low traffic pavement structures tested on the LCPC accelerated pavement testing facility. A simplified method using an elastoplastic model for permanent deformations of unbound granular layers allow to estimate the vertical displacement of the structure.

This method is based on three steps :

- The material is characterised using repeated load triaxial tests, with different stress levels.
- The tests results are analysed using a model of prediction of permanent deformations. The model selected is an elastoplastic model developed by C. Chazallon [1]. A finite element analysis, with the program CESAR-LCPC, is used to determine the stress distribution in the pavement, and subsequently the permanent deformations.
- The permanent strains are integrated along the vertical direction to obtain the vertical displacements in the structure (i.e. rutting of the layer).

TRIAXIAL TESTS ON UNBOUND GRANULAR MATERIAL

The repeated load triaxial tests were performed with a triaxial apparatus for subgrade soils, designed for 76 mm diameter specimens. A new approach proposed by G. Gidel [2] was adopted for cyclic triaxial tests. It consists in applying cyclic loadings where the axial stress and the confining pressure vary in phase (different stress paths with constant stress ratios q/p).

MODELLING OF PERMANENT DEFORMATIONS

The elastoplastic model for permanent deformations recently developed by C. Chazallon (2000) is based on the yield function and plastic potential of the non associated model of Hujeux [3] in its simplest formulation.
The yield function is given by :

$$f = \sqrt{\frac{27}{2}}\frac{S_{II}(\underline{s}-\underline{X})}{MI_I(\underline{s}-\underline{X})} + rb\ln\left(\frac{I_I(\underline{s}-\underline{X})}{3p_c}\right)$$

where I_I is the trace operator, S_{II} is the deviatoric stress operator, b is a parameter which controls the shape of the yield surface in the (p, q) plane. M is the slope of the critical state line in the (p, q) plane and p_c is the critical pressure corresponding to the actual void ratio.

This equation is completed by the definition of a non associated plastic potential g and the following kinetic :

$$d\boldsymbol{e}_p = d\boldsymbol{l}\,\frac{\partial g(\underline{\boldsymbol{s}},\boldsymbol{a})}{\partial \underline{\boldsymbol{s}}}$$

where

$$g = \sqrt{\frac{27}{2}}\,\frac{S_{II}(\underline{\boldsymbol{s}}-\underline{X})}{MI_I(\underline{\boldsymbol{s}}-\underline{X})} + \ln\left(\frac{I_I(\underline{\boldsymbol{s}}-\underline{X})}{3p_c}\right)$$

The model includes both isotropic and kinematic hardening, and allows to simulate cyclic loadings with large numbers of load cycles. Three hardening variables are used :

- the hardening variable associated to the volumetric plastic strain is given by :

$$p_c = p_{c0}\exp(\boldsymbol{b}\boldsymbol{e}_v{}^p)$$

where $\varepsilon_v{}^p$ is the volumetric plastic strain. p_{c0} and $\boldsymbol{b}$ are parameters of the model.

- r is the hardening variable associated to the deviatoric plastic strain :

$$r = r_0{}^{el} + \frac{\boldsymbol{e}_d{}^p}{a+\boldsymbol{e}_d{}^p}$$

where $\varepsilon_d{}^p$ is the deviatoric plastic strain. $r_0{}^{el}$ represents the initial elastic domain and a controls the evolution of r.

- $\underline{X}$ is the tensorial kinematic hardening variable. Except at the first loading, X describes the origin of the charge surface.

$$\underline{X} = \underline{\boldsymbol{s}} + P\underline{I}$$
$$d\underline{X} = m\,d\underline{\boldsymbol{s}}$$

The elastic part of the model is described by the non linear elastic Boyce model.

Three types of tests are performed to determine the parameters model :

- Monotonic triaxial tests are performed till failure at different confining pressures,
- Cyclic triaxial tests with low number of cycles to determine the non linear elastic Boyce model parameters,
- Cyclic triaxial tests with different q/p ratios and 80000 cycles per stress level to determine the cyclic plasticity parameters.

The effect of the different model parameters on the modelling predictions is analysed and discussed.

FINITE ELEMENT CALCULATIONS

A finite element analysis (in 3D), with the program CESAR-LCPC, is used to determine the stress distribution in the pavement. The calculation is performed with the module CVCR, dedicated to pavement structure calculations, and which includes non linear elastic models for unbound granular materials, and visco-elastic models for bituminous materials. The model is applied to calculate the rutting of pavements structures, using the following approach :

- Choice of points (y, z) in the plane perpendicular to the direction displacement,
- Determination at each point of the stress path $\underline{s}(t)$,
- Utilisation of $\underline{s}(t)$ to calculate $\underline{\underline{e}}^p$ at each point, with a fixed number of cycles,
- In a first time (using the simplified method), the permanent strains are integrated along the vertical direction to obtain the vertical displacements in the structure (i.e. rutting of the layer).

The method is illustrated in an example.

Références

[1] Chazallon C.: Elastoplasticity framework for incremental or simplified methods for unbound granular materials for roads. BCRA, 2002.
[2] Gidel G.: Comportement et valorisation des graves non traitées calcaires utilisées pour les assises de chaussées souples. PhD Thesis, Université Bordeaux 1, 2001.
[3] Hujeux J.C.: Une loi de comportement pour le chargement cyclique des sols, in Génie Parasismique, Presse des Ponts et Chaussées, Paris pp316-331. 1985.