Elasto-plastic constitutive law based on evolving soil structure

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Engineered barrier system for underground nuclear waste disposal involves compacted soil upon unsaturated conditions providing peculiar properties to the material linked to its double structure. Compaction at the dry side of optimum induces an aggregated structure to the soil (Delage et al. 1996). After closure of the disposal, this engineered barrier is submitted to a re-saturation process. At long term, and mainly close to the host rock, the material is fully re-saturated while the microstructure is still aggregated.

The objective of this work is to propose a new constitutive model for such a kind of aggregated soils based on the evolution of pore size distribution along mechanical loading. A physical significance of the structure variable is given by the tracking of the pore size distribution along different compression states. The soil is considered as fully structured when it exhibits a fully developed bi-modal pore size distribution while this structure variable vanishes when the pore size distribution shows a single mode of pore sizes. Particularly, in Figure 1 for a silty soil, different initial microstructures have been obtained from different compaction conditions (dry side of optimum, Fig. 1a; wet side of optimum, Fig 1b). Then, the subsequent loading affects the pore size distribution, mainly for the aggregated soils.

From a constitutive point of view, this evolving microstructure is taken into account through the structure variable that tends to unity when the microstructure passes from bi-modal pore size distribution to a uni-modal distribution. This structure degradation is linked to the generation of volumetric and deviatoric plastic strain.

Strictly speaking, the model is based on the ACMEG model developed for remoulded unsaturated soils (Francois and Laloui 2008) and extends it through the consideration of a structure variable. Irreversible strains are considered through two inter-connected plastic mechanisms. The isotropic mechanism is activated upon hydrostatic loadings while deviatoric mechanism is mobilised upon deviatoric stress states (Figure 2). The apparent preconsolidation pressure (p'c) is the link between both mechanisms. In addition to the conventional strain hardening, the structure variable modifies the apparent preconsolidation. Finally, progressive mobilisation of plasticity can also be activated inside the bounding surface in order to control the smooth transition between elastic and plastic responses. This is particularly well-appropriated for soil with a dispersed structure. The proposed model follows the main concept of the models for structured soils as developed previously by various authors (Kavvadas et Amorosi 2000, Nova et al. 2003, Liu et al. 2013, among others). The new ingredients are related to the double mechanism of plasticity that distinguishes structure degradation induced by deviatoric and isotropic loading.

This model is validated by comparison with experimental results (triaxial and oedometric compression tests (Figure 3)) obtained on re-saturated soils compacted at different moisture contents (in order to generate different microstructures). Also, triaxial tests on heavily overconsolidated soils were carried out to highlight the deviatoric behaviour of isotropically-destructured soils.

References

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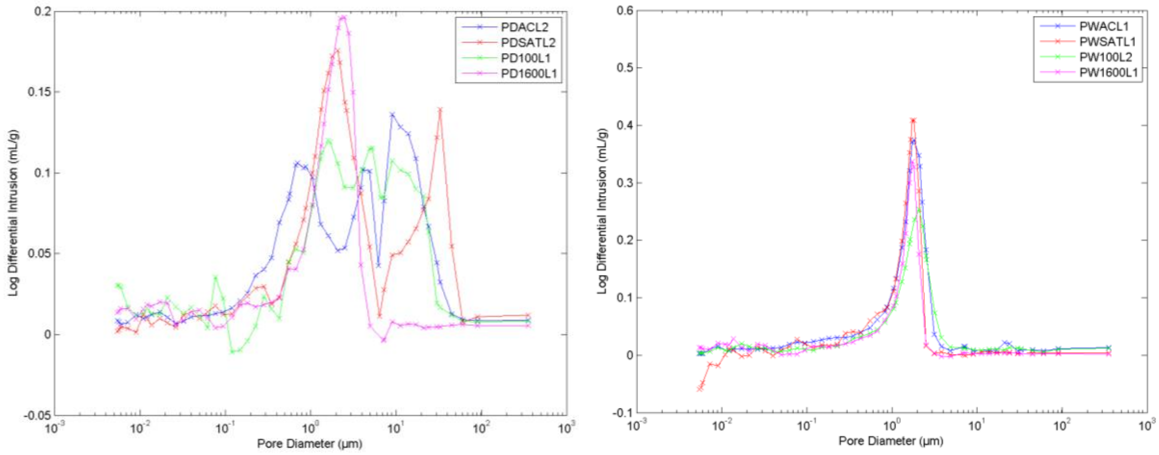
Illustrations



(a) (b)

Figure 1: Pore Size Distribution of soil: (a) structured soil, (b) unstructured soil. As-compacted state (blue), saturated (red) and loaded in an oedometer at 100 kPa (green) and 1600 kPa (magenta)

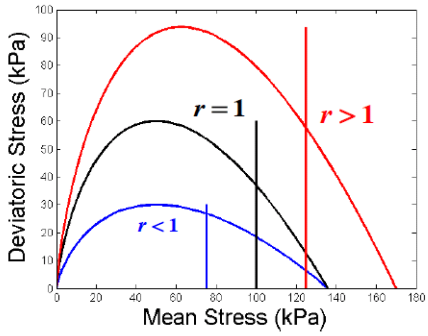


Figure 2: Elastic domain delimited by deviatoric and isotropic Yield Limit. r is the structure variable

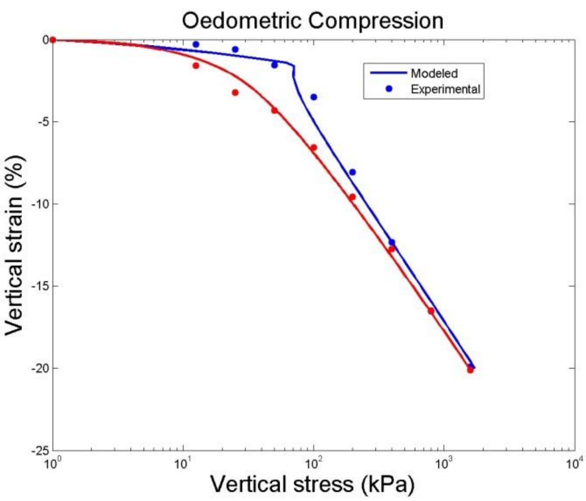


Figure 3: Modeling (solid line) of oedometric compression tests carried on structured (blue) and unstructured (red) soils

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