Experimental and numerical investigations of puncture failure of geomembranes lining systems.

Research thematic: Experimental work and modelling in geomechanics

Context and problematic of the thesis subject

Geomembrane lining systems are complex systems that associate granular layers and geosynthetics. These systems enable to combine both drainage and barrier functions. Geomembrane lining systems are key components of any lying hydraulic structures on highly permeable ground (e.g. high-altitude dams for artificial snow production, cf Fig. 1) or dealing with polluted water (e.g. landfill in which drainage water must be collected without leakage). Indeed, the sealing system durability is necessary for the integrity of the structure because any breakage in the sealing could induce significant consequences for public health, safety and goods through dam failure or environmental pollution.

Figure 1 – PVC geomembrane of an altitude reservoir dedicated to the production of artificial snow ; geomembrane showing repairs due to damage by puncturing actions

In lining systems, sealing is ensured by a geomembrane that can be made with various polymeric compositions. Drainage function (below and above geomembrane depending on the application) is generally ensured by a granular layer. In most cases, a vertical stress applies on the whole lining system, which may induces puncturing actions in the granular bed, possibly leading to localized failures in the sealing system. To this respect, a geotextile can be used to protect geomembranes against puncturing actions. This geotextile is in most cases a non-woven needle-punched product. To ensure the durability of the structures that include lining system, the design of geotextile is a major issue.

This thesis project aims to investigate the protection of geomembranes against puncturing stresses by the use of non-woven needle-punched geotextiles. This will be addressed through laboratory experiments and numerical modeling using discrete element modeling (DEM).

The main research questions that will be investigated are:

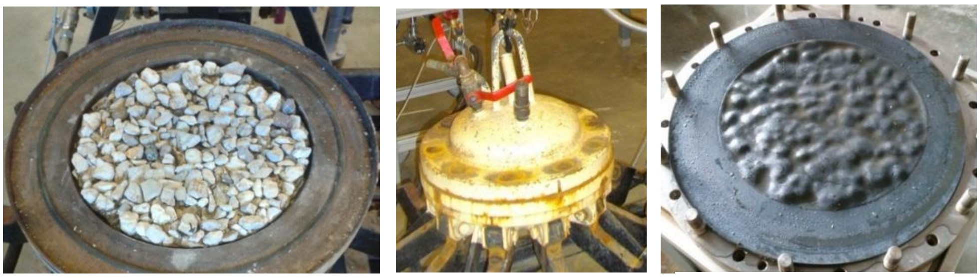
- What is the driving mechanism of geomembrane failure subjected to puncturing actions? In other words, what is the relative contribution of compressive, shear and tensile forces with respect to failure?

- Does DEM make it possible to model the failure of a geomembrane subjected to puncturing actions?

- Does the DEM make it possible to model a geotextile sheet providing a protective effect against the rupture of a geomembrane subjected to puncturing actions?

Research program

This thesis project plans to develop original experimental physical models in order to describe all the mechanisms involved in the puncturing phenomenon and to extend recent DEM developments to model various types of flexible sheets as well as fibrous materials in interaction with a granular material. The useful characteristics of the mechanical behavior of geomembranes will be obtained by laboratory tests. On the experimental side, testing devices (compression / tension press, a hydrostatic pressure cell displayed in Fig. 2, as well as a shear bench) from the geosynthetics laboratory of UMR RECOVER will be used.



Bearing granular material | Hydrostatic pressure cell | Damaged PVC geomembrane

Figure 2 – PVC geomembrane stressed in a hydrostatic pressure cell, and damaged by puncturing actions induced by a granular support

From laboratory campaigns measuring the resistance of geomembranes under simple stresses (compression, shear, traction), the various constitutive mechanical behavior of these materials will be characterized (elastic-brittle with different stiffnesses and different resistances, elasto- plastic with very diverse ductilities (elongations at break), even visco-elastic) Then, a 3D laser scanner will be used to digitally reproduce the geometry of the blocks used in the laboratory experiments (Fig. 3). This will enable to construct a digital twin of the laboratory experiments in DEM framework thanks to Level-Set technique. Thanks to the discrete nature of DEM, the perforation of geomembranes can be described naturally. However, DEM has not yet been used for geomembranes and the present project will open new perspectives on the modelling of their mechanical behavior. In particular, we will seek to estimate the predictive performances of DEM methods for such studies, from experimental tests corresponding to the puncturing of geomembranes of different nature. In particular, we will focus on using the micromechanical data accessible in DEM to specify the mechanical state of the different areas of the membrane and characterize the failure modes consistent with the experimental data. By then focusing on geotextiles for the protection of geomembranes, we will also seek to build numerical models of a second level of complexity, taking into account the microstructure of real products (Fig. 3). The modeling of microstructural parameters therefore represents a very innovative work and absent to this day from the scientific bibliography of geosynthetics.

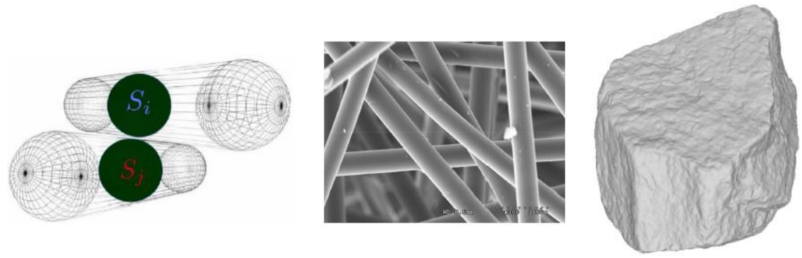


Figure 3 – Fibrous elements in DEM, left, from Kunhappan et al. (2017), which this research subject proposes to apply to geotextiles such as that seen with Scanning Electron Microscopy, center. (D. Kunhappan, B. Harthong, B. Chareyre, G. Balarac, and P. J. J. Dumont. Numerical modeling of high aspect ratio flexible fibers in inertial flows. Physics of Fluids, 29(9): 093302, 2017). Laser scanned boulder in 3D to construct the digital twin model, right (courtesy of J. Duriez).

Framework of the thesis

The doctoral student will be registered at the Physics and Material Sciences doctoral school of Aix-Marseille University (https://ecole-doctorale-352.univ-amu.fr/) and will be based in the RECOVER unit of INRAE PACA (https://www6.paca.inrae.fr/recover/). One of RECOVER's research thematic relates to the short (resistance) and long term (durability) behavior of geomaterials. This research unit is equipped with experimental benches and technical means for the characterization and study of the hydraulic and mechanical behavior of granular materials and geosynthetic materials. RECOVER also disposes of significant computing facilities and scientific expertise for the modelling of geomaterials with DEM simulations.

Researchers from RECOVER are well identified in international research networks such as ALERT geomaterials or IRN GeoMech.

Contract period: 36 months from 2021 October to 2024 end of September.

Workplace: Inrae site d'Aix-en-Provence / Le Tholonet (France).

Doctoral school: ED 353 Physics and Material Sciences doctoral school of Aix-Marseille University

Expected profile and requirements for the position:

Master of research or graduate in geotechnical engineering – civil engineering - materials science. The candidate is expected to have strong knowledge in solid mechanics. A training course in numerical modelling or a past experience in laboratory work will be profitable.

Expected skills: motivation for research work, faculty for working independently and in a team, capability to formulate concepts, curiosity, constructive criticism, patience, perseverance and scientific rigour.

A good level in English is mandatory.

Keywords: geomembrane, geotextile, puncturing, failure behavior, discrete elements modelling.

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