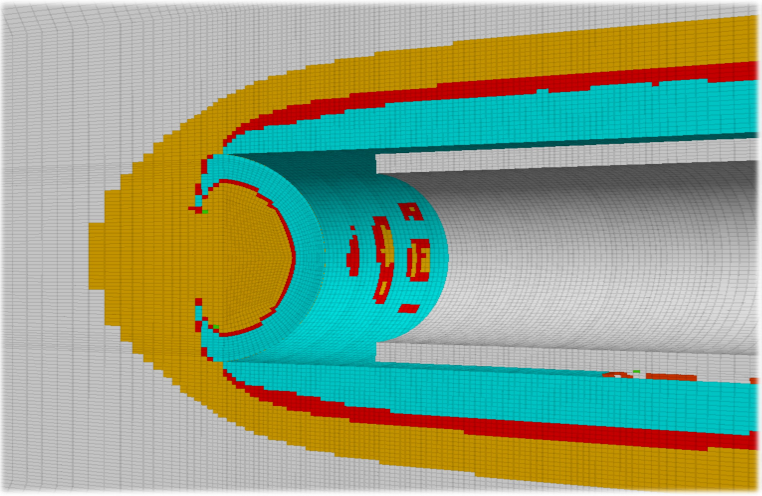


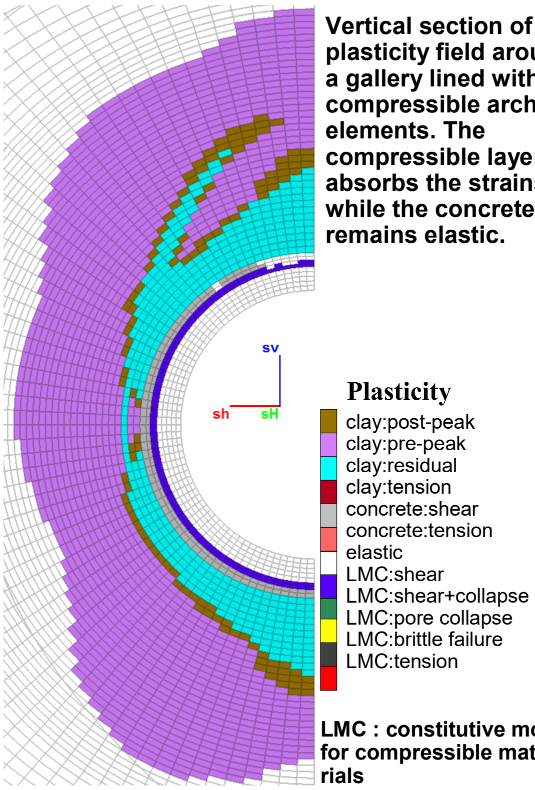
3D Modelling of geostructures with complex rheology: excavation of a gallery lined with compressible arched segments

The construction and operation of deep underground structures in the safest conditions relies on the development of innovative technologies. In order to assess the performance of the support provided by compressible arched monobloc segments to a tunnel excavated using a boring machine, the National Institute for Industrial Environment and Risks (Ineris) has developed and implemented a complex numerical model of the underground structure surrounded by a viscous and anisotropic host rock.

Context. Since 1999, the National Agency for the Management of Radioactive Waste (ANDRA) has been operating the Meuse/Haute-Marne underground research laboratory located at a depth of 500 metres. The purpose of this laboratory is to assess the feasibility and safety of a radioactive waste repository located in a deep geological formation.

An experimental project carried out in this laboratory had the aim of comparing and testing various solutions for underground gallery support, in particular those consisting of compressible arched monobloc segments. This innovative technology enables absorbing large convergence strains from the gallery wall thanks to a thick and compressible layer made of small prefabricated clay shells. This layer enables to limit the compressive forces of the surrounding rock on the second annular component of the segment, which is made of concrete.

With the help of numerical 3D modelling, INERIS has provided its expertise to interpret the in situ measurements made during this experiment and to predict the very long-term behaviour of the gallery and the structural elements used in the different sheathing options studied.



Vertical section of the plasticity field around a gallery lined with compressible arched elements. The compressible layer absorbs the strains while the concrete remains elastic.

LMC : constitutive model for compressible materials

The adopted approach. The specific behaviour of the argillites composing the surrounding rock medium required the development of a strain hardening elastoviscoplastic model, which was pre-validated from the simulation of gallery excavations with different orientations.

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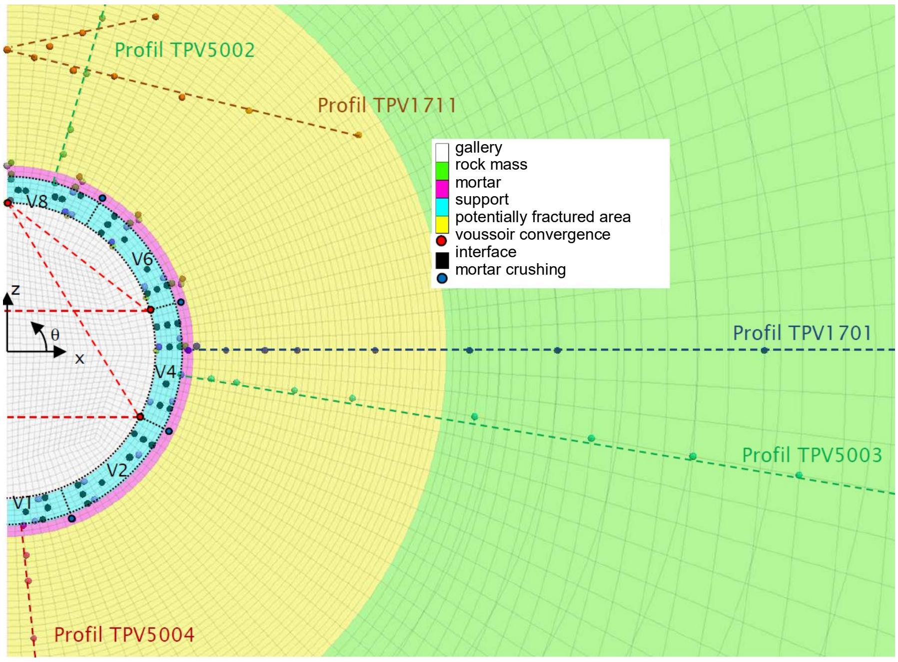
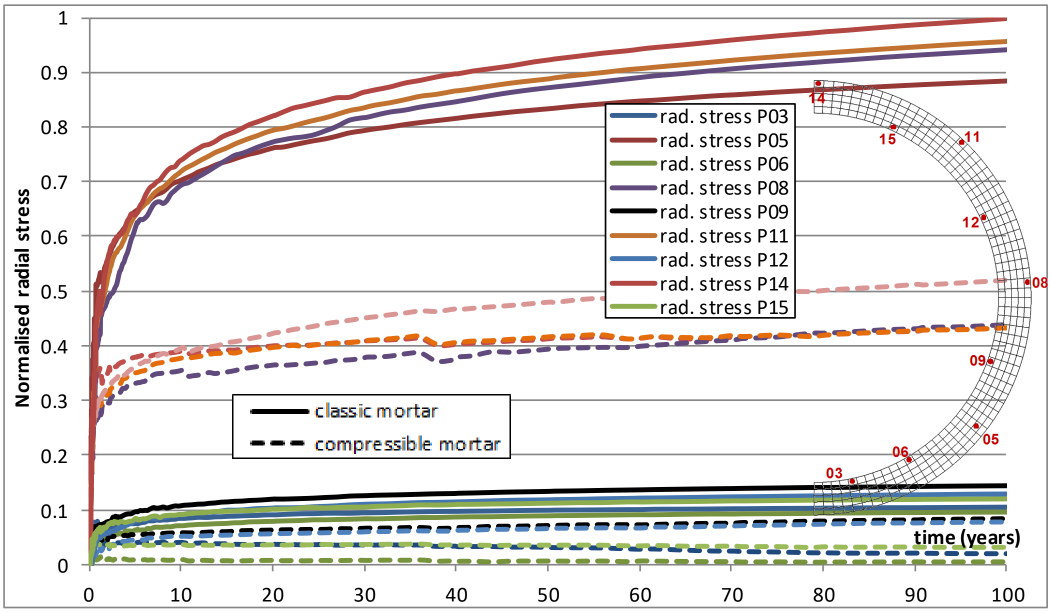


Representation of the virtual sensors positioned within the numerical model

The three components constituted of the sheathing, the structural support and the mortar were explicitly represented in the model, which enabled simulating the geometric phasing of their installation and that of the excavation. Each of the geomaterials concerned had been assigned a specific rheological model: pure elastoplastic, for backfill mortar and sprayed, poured or prefabricated concrete and double threshold elastoplastic (shear and compressibility), elastoplastic for the compressible material. The sheathing-mortar interface was also considered, with time-dependent normal and tangential stiffnesses.

More than 200 virtual sensors were positioned in the numerical model so as to calculate the time history of variables during the simulation of excavation, to be compared with those of the experimental setup made of extensometers, inclinometers, convergence meters, stress and strain sensors, as well as mortar compression sensors on the extrados of the arched segments. Based on the simulations performed on a high-end computing workstation, aids for the comparative analysis of the tested support solutions could thus be provided to ANDRA in order to evaluate the most efficient solution from the viewpoint of safety, environmental impact and implementation cost.



Time history of radial stresses within the arched segments with classic mortar (solid lines) and compressible mortar (dotted lines): the compressible material reduces the amount of radial compression transmitted to the concrete in the arched segment.

Lessons learned. The development of new industrial uses of ground and underground environments raises safety and cost-benefit issues that can only be resolved in a satisfactory manner through innovation. The precise evaluation of the performance of innovative components at the heart of a complex underground project, in a near-surface or in a deep environment, is difficult to envisage without the use of numerical modelling. The simultaneous consideration of the various physical phenomena impacting a complex geostructure in a deep underground environment poses real challenges for experts. Multi-physical numerical modelling, validated on real cases through cutting-edge expertise, makes it possible to parametrically predict the performance of the project and constitutes an essential decision-making aid.

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