Summary

Brittle failure of rock around deep tunnels, often referred to as spalling or rockburst, is characterized by the sudden and violent fracturing of the rock mass surrounding the excavation. It is a complex phenomenon whose mechanisms are not yet fully understood, and for which standard predictive method has not been commonly accepted so far. As a consequence, this kind of failure poses significant challenges to underground excavation operations, jeopardizing both the safety of personnel and the structural integrity of openings.

Recent years have seen a significant increase in the number of deep tunnels being excavated around the world, driven by a growing demand for natural resources, underground infrastructure, and energy projects. This increase of construction works at great depth led to the emergence of critical issues related to the brittle failure of the surrounding rocks, and highlighted that the proper identification of the rock mass failure mode is a crucial task in the design process of a deep tunnel.

Focusing on brittle collapse phenomena not governed by the geostructural conditions of the rock mass, this research introduces a novel, analytical approach to differentiate between ductile and brittle failure of rock around deep tunnels. The approach is grounded in two mechanical models of rock damage specifically developed to describe the brittle and ductile failure of the rock mass, as a result of the stress release resulting from the excavation. These models have been developed by overcoming some simplifications and shortcomings of the analytical solutions currently available in the literature, although they share with them the basic approach.

The application of such models is channeled into the definition of a new brittleness index, called TBI (Tunnel Brittleness Index), which describes the outcome of the competition between two opposing failure mechanisms (brittle or ductile), estimating the proneness to brittle failure of the rock around deep tunnels. TBI is obtained through a modular process that lends itself well to future improvements and, unlike other available empirical brittleness indexes in the literature, is based on modeling the actual rock failure processes, considering the variations in stress and energy induced by excavation. The validation of TBI has yielded promising, albeit preliminary, results, suggesting that it may, in the future, be employed for predicting brittle collapse in the early stages of deep tunnel design.

Subsequently, an experimental activity is described, planned and carried out based on the analysis of one of the most critical input parameters of TBI. The primary objective of this activity was to study the mechanical and morphological characteristics of splitting fractures in rock, such as those occurring in brittle collapse phenomena around cavities. The experimentation encompasses mechanical tests for the rock characterization, fracture roughness analyses, ultrasonic measurements for assessing the stiffness of closed fractures in rock, and compression tests on fractures. The results obtained and the knowledge acquired yielded valuable insights into one of the most uncertain and critical parameters of TBI, known as λ. These findings are expected to be beneficial to future studies aimed at defining a dataset and a robust and repeatable estimation method for λ, being an important contribution to the application of TBI.

The work conducted has identified interesting potential continuations and extensions of the research described here, which are believed to offer important advancements in the understanding and management of brittle failure phenomena in deep excavations.