The art of rock engineering design and the need for research

Rock Engineers and mine personnel frequently disagree on design aspects. These disagreements can lead to poor designs or failures. A number of large collapses have occurred in the bord and pillar mines and open cast mines in the Southern Africa region in the last two decades. Can we learn from the decision-making that led to these collapses and improve? Philosophy offers the opportunity to adopt a reflective learning approach.

ChatGPT gave an interesting insight into this aspect of mine design. Rock engineering is less of an exact science than other engineering disciplines and it is suggested that rock engineering design is best described as a "science-based art".

The science provides the foundation and design is based on aspects such as rock mechanics principles (e.g., stress-strain behaviour, and failure criteria), empirical methods (e.g., Q-system, and RMR), numerical modelling (e.g., finite element, distinct element, and boundary element methods), monitoring and instrumentation (e.g., extensometers and stress cells) and geological and geotechnical data (e.g., boreholes, core logging, and lab tests). The designs are never purely scientific owing to reasons such as natural variability of the rock mass, the geology is complex and discontinuous, the uncertainty caused by incomplete or generalised data, decisions must often be made with partial information, when conditions change the designs must evolve, and balancing performance, cost, and safety is not purely technical.

Based on these considerations, it implies that "industry standard" criteria for design neither are always the best technical solutions, nor does it imply these criteria are correct. Davide Elmo and his co-workers explored this topic and examined rock engineering using a philosophical approach (Elmo et al., 2022) in *Examining Rock Engineering Knowledge through a Philosophical Lens. Geosciences*. They noted that rock engineering designs are shaped by cognitive biases, which over time have created a dogmatic barrier to innovation. Almost no attention has been given to the impact that subjectivity, human factors, and lack of scientific replicability have on the empirical design methods used in this field.

As a complicating factor, the modelling methodologies and constitutive codes typically used are difficult to calibrate and represent a universal challenge for the application of rock engineering models. As more complex numerical models are developed for the improved simulation of observed rock mass behaviour, more onerous requirements of model calibration and user expertise are required. This applies to boundary element models, finite element, and finite difference codes. Elmo et al. (2022) made the following important observation: "It is evident generally that if older and simpler solutions have a clear advantage in terms of durability and/or efficiency, even if this advantage is restricted to a limited purpose, they continue to exist and evolve." In his 2003 Presidential Address: *Rock engineering – good design or good judgement*, T.R. Stacey recognised this problem and noted that rock masses are so complex that realistic modelling, even with sophisticated methods, is impossible. Simple elastic models with good engineering judgement may therefore continue to exist as one of the practical rock engineering tools.

As a first step to mitigate the uncertainty in rock engineering and the challenge described in this note, Elmo et al. (2022) emphasised that for research, critical thinking needs to be applied and the foundations of rock engineering as an empirical science should be questioned. Furthermore "*replication*" research should be conducted as a more rigorous form of review compared to the traditional peer review. A recent example of replication research is given by the Le Roux and Malan paper (2024). Researchers need to provide full information to allow others to replicate their work. Very often the assumptions used for numerical modelling of layout design are not given in design reports and these need to be included in the reports.

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