# How to form competent rock engineers

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ABSTRACT: The profession of a rock engineer is not defined in any academic curriculum. We discuss the professional requirements for civil engineering or mining engineering applications and recommend the necessary classes to form a competent rock engineer. Emphasis is placed on the knowledge about the creation of the appropriate geological and geotechnical model through abstraction of results from site investigation and rock mechanical principles. Design analysis and constructability are further important parts in rock engineering education. The key challenge is, however, to recruit students into entering this rewarding professional career and to provide proper education to them. As most universities tend to hire basic scientists there is little conveyance of personal experience from rock engineering practitioners and little appreciation for rock engineering works.

*Keywords: Rock Engineering, Education, Professional requirements, Career satisfaction.*

## 1 INTRODUCTION

There is a consistent demand for competent rock engineers for both, civil engineering, and mining projects. However, few university entries choose this demanding career path although it is one of the most fulfilling professions that can be exercised. It is true that the presently advertised work-life balance is difficult to achieve when the site is not near home or at remote places. However, the benefits in terms of income and professional satisfaction go along with growing competence gained from lifelong project work with rock masses.

How to inspire young people to choose rock engineering as a career and to get competent in that area? The goal must be to teach students how to make design decisions with incomplete information about the proper geological model, with strong but not necessarily correct assumptions about the mechanical behavior of a rock mass in response to excavation and the ability to evaluate the ever more sprawl of numerical models by applying the principles of mechanics. Towards this, appreciation of sketchy geology, rock mechanical basics and construction technology should be enthusiastically taught by academics AND practitioners who experienced their shares of failures in rock engineering issues. The very nature of failure is inherent in rock engineering and should be embraced as necessary backslashes towards the development of personal competence.

## *1.1 What is a competent rock engineer?*

Interestingly, the profession of a rock engineer is not defined. Civil engineers and sometimes mining engineers as well as engineering geologists claim that title and competence. It is true that in most mining universities there is a branch dealing with rock mechanics. Examples are Colorado School of Mines and Penn State University in the USA, University of Vigo, Aalto University and Lulea Technical University in Europe, Queen's University in Canada or Monash University in Australia, to name a few. In Europe, rock mechanics is mainly associated with civil engineering departments which convey professional titles such as ground engineer or geotechnical engineer. Often, just one course about rock mechanics is taught focusing on a pure mechanistic approach as well as on numerical methods. The outcome is a geo(technical)-engineer without deep knowledge about the geologic media, namely the rock mass. This concept of a geo-engineer stems from the mid 1990's as described by Barla (2008) (Figure 1).
Burland (2006) defines the geotechnical problem as being based on four criteria:

- the ground profile,
- the mechanical behavior of the soil,
- prediction using appropriate models, and
- empirical procedures based on judgment and experience.

The adaptation to rock engineering may read like as follows. A rock engineering project, and thus the knowledge of a rock engineer, involves:

- A geological model from site investigation incorporating the 3D-extend of rock types and rock structures (i.e., faults, folds, discontinuities). This model leads to long- and cross-sections way beyond the sought engineering structure. Estimates about the state of stress and groundwater conditions define the boundary conditions for the geological model.
- The mechanical behavior of rock masses with respect to excavation works (drill and blast (D&B) or mechanical) as well as to support measures for the desired stability. This includes estimates about strength, deformability and conductivity of discontinuities and rock, derived rock mass strengths and deformability, and weatherability of the rock mass for the design life of the structure. Note that safety levels and design life are different for mining and civil engineering structures in rock.
- The actual design process involves analytical, numerical and observational methods obeying a sound concept for constructability. This step leads to construction and support procedures, advance rates, timelines and material flows to ensure progress on schedule.

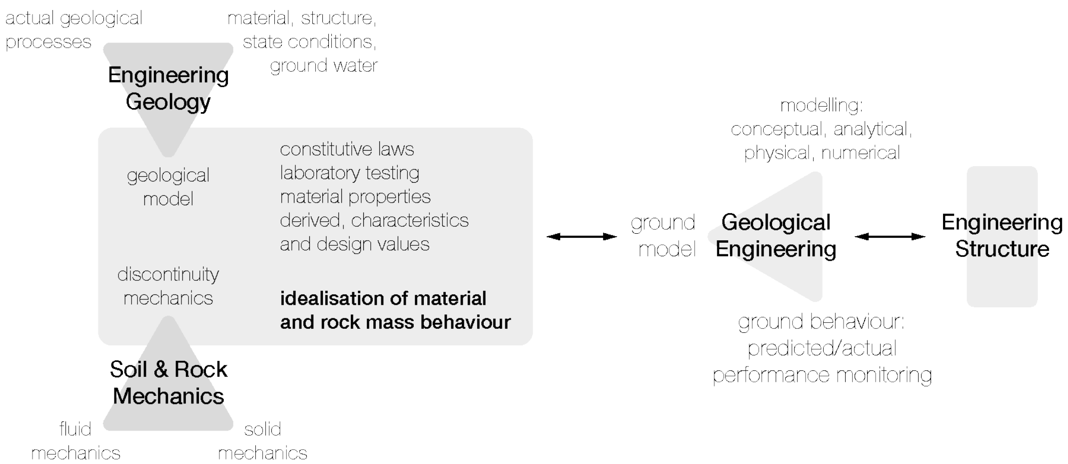


Figure 1. The position of soil mechanics, rock mechanics and engineering geology and the associated sister societies within the broader field of geo-engineering (rethought from Barla, 2008).

- The final step in a rock engineering project is documentation, i.e., comparison of anticipated geological model and of the rock mass behavior with the actual situation found at the site. This step involves geological-geotechnical mapping, check of advance rates and suitability of support measures. This feedback is looped in all previous steps and the ensuing changes improve the project.

It is not necessarily the rock engineer to actively participate in all steps of the project. She or he should however be able to understand how the geological setting was developed from geological maps, from geotechnical mapping of outcrops and from the interpretation of drillings or geophysical surveys. It must be clear to a rock engineer, that the geological / geotechnical model is a hypothesis from engineering geologists. The hypothesis gets better (i.e., more accurate) when executed by knowledgeable and experienced “seasoned” geologists but it will still be an educated guess. The rock engineer should also understand that the assigned mechanical properties of the rock mass are nothing but “putting numbers to geology” (Hoek, 1988) without ever having the chance to verify those properties.

The design of structures in and on rock mass is executed by assigning properties to the geological model and subject this geotechnical model to numerical simulation. There should be a clear anticipation about the failure modes, either stress related failure or structural failure. Outputs of numerical modeling are displacements, secondary stresses, and safety factors for example. A suitable support system may be simulated to control the displacements. Knowledge of construction technology is a must.

Finally, during the excavation process the rock engineer should compare the encountered geology with the geological model, compare the encountered geotechnical properties with the ones estimated in the geotechnical model, check the actual failure modes and displacements with the predicted and adjust the support system accordingly. Moreover, the actual advance rates of tunneling / mining must be observed and effects for the project schedule should be determined.

In summary, a competent rock engineer has to have knowledge about geology, geotechnical parameters and rock mechanical principles, about numerical modelling, support systems, and has to have the wits to relate new information during the excavation process to changes in the design. Most of all, a competent rock engineer has to make sound decisions fast under incomplete information about geological / geotechnical conditions.

## 2 CURRICULUM FOR ROCK ENGINEERS

It has been pointed out earlier that rock engineer is not a defined profession with a specific curriculum. There is little rock engineering teaching with respect to the requirements stated previously. This contrasts with education for engineering in soils. Particularly in Germany the coursework for the MSc-degree in civil engineering includes soil mechanics and soil engineering. Most curricula for geotechnical engineering feature a rock mechanics course without appreciation of geological / geotechnical procedures or models. Often, very extensive numerical modeling coursework takes place. The latter is considered an overkill as in practice almost all projects are modelled based on isotropic material conditions although nearly all rock masses are anisotropic. For mining engineers, rock mechanics is also taught but always concentrated on the given mining methods. The teaching of geology for engineering is always confined to a very early course in the BSc curriculum without any real connection to projects to be later dealt with by the rock engineer.

In engineering geology courses focus is often placed on standards and procedures for the geotechnical description of rock and rock masses. The development of a geological model for engineering purposes is often neglected. Same applies for practical skills such as drillcore logging and the development of geological / geotechnical sections. The estimation of rock mass properties by using engineering classification systems (GSI, RMR, Q) is often taught. Surface mapping is thought to be an “unscientific” skill and tends to be neglected by many universities as it is time-consuming and often frustrating work. Same applies to underground geological mapping.

Many universities fell to the global hype for excellence since 2000 and since then mostly hire scientific personnel with a high publication record but without own practical experience in civil, mining or geological engineering. Anybody who experienced failures in rock engineering issues can confidently convey that the very nature of failure is inherent in rock engineering and should be embraced as necessary backslashes towards the development of personal competence.

In the case of Spain, the education of mining engineers was traditionally based on 6-year studies which included field practice, visit to mines and short contracts in companies. The implementation of the EU Bologna agreement in higher education, have changed the 6-year approach to a 4 + 2 one including a degree, with a more limited curriculum in basic sciences including geology, and a master. Additionally, increasingly stringent regulations in terms of safety, have made more difficult for universities and companies the development of field work and visit to mines, with the corresponding detrimental effects in the capabilities of engineers.

A sound basis in geology and engineering geology appears to be a must for rock engineers. Understanding of geology and structural geology is a slow and time-consuming process. It is acquired from lectures (mainly ideal textbook geology which is not easily encountered in reality) and from fieldwork. So, any substantial gain in knowledge comes from observation in situ. The saying "The best Geologist is [s]he who has seen the most rocks" holds true even and particularly in digital times. Nothing is as important for a rock engineer than having the demanding experience of surface mapping, when only a few outcrops exist, and a fully colored map must be delivered. Core logging and the extraction of sections is also a great source for understanding the ambiguousness of a geological model. Here it gets clear that a geological model is always a hypothesis which had to be factored-in towards a sound design.

Moreover, linking the basic geology to the effects of construction in rock mechanics terms implies a simplified geological model where relevant geological features should be considered and quantified in rock engineering terms, but not all details of geology are relevant. As put forward by Fairhurst (1993) mere increase in the sophistication of mathematical formulation of a problem is of little value if the correspondingly required physical details are not available. Conversely, acquisition of experimental data without guidance from theoretical hypothesis is at best expensive and wasteful, and often misleading.

Other important areas to be taught to a competent rock engineer are:

- Rock mechanics, focusing on stress-displacement relations of rocks and rock masses as well as stress transformations, will provide the necessary theory for the design of structures in rock.
- Construction technology covers the different excavation methods (D+B, TBM, roadheader, impact hammer etc.) as well as the support measures (bolts, shotcrete, mesh etc.).
- Mining methods cover the excavation processes to recover resources from seams and ore bodies.
- Numerical, analytical and empirical methods aid to decide about support measures to ensure safe and economic project delivery.
- Contractual and legal aspects as well as technical standards cover the framework of any rock engineering project.
- Controlling / business administration covers the financial and personnel boundary conditions that in fact dominate all projects in rock.
- Rock engineering is the application and integration of all the items above towards transforming a project in rock to reality.

Table 1 compiles what the authors consider to be a suitable curriculum for a competent rock engineer, which unfortunately tend to differ of the actual curricula for most degrees in mining or civil engineering in European universities.

## 3 TEACHING APPROACH

Competence is acquired through education, training and experience at school, at university and at work. Mainstream suggests that mining, and to a certain degree, civil engineering as well, are evil so that young people are skeptical to choose that profession (accept that you don't get likes being a mining or an excavation engineer). Poorly understood environmental awareness have contributed to present mining or civil engineering works as dirty and unpleasant, and this is sadly so reflected even in primary school books in some European countries. Often young people do not connect the facts of having available energy or a cell phone with the necessary mining of the raw materials to produce these basic commodities, usually taken for granted.

Table 1. Curriculum for a competent rock engineer.

| | |
|---|---|
| Basic Sciences | Mathematics, Physics, Chemistry |
| Geology | Geomorphology, physical geology, petrography, sedimentology, structural and regional geology |
| Applied mechanics, material science, hydrogeology and basic geophysics | |
| Civil Engineering Tasks | Underground (tunnels, caverns). Surface (slopes, roads, railways) |
| Mining Engineering Tasks | Underground mines for seams and orebodies, surface mines, mining methods |
| Engineering geology | Properties of rock and rock masses, rock mass characterization, understanding of the mechanical behavior of rock and fractured materials |
| Practical geology | Surface and underground mapping, core logging, discontinuity mapping, preparation of geological maps and sections, field camps |
| Rock Mechanics | Mechanics of rock and fractured rock, failure criteria, stresses and displacements |
| Analyses and design of structures on, in and with rock | |
| Construction and mining technology; Legal, contractual, standards; Writing and communication | |

At young age experience may be gained through play (e.g., in the sand-box building sandcastles) but this is replaced by virtual marks from 2D flat screens. Basic algebra, trigonometry and calculus are not anymore properly taught at school. School-leavers should be able to communicate concrete and abstract ideas through speech, the written word and, particularly, by hand drawn diagrams. Sadly, many university entrants do not have these skills.

The internet and widespread use of smart phones has also had a major impact on learning styles. Members of Generation Z have grown up in a world that is always connected. The answer to any question is just an internet search away. Generation Z students have access to more resources than ever before, but they need assistance in learning how to process the information. Students are conditioned to expect information will be readily available via search engines, recent developments such as artificial intelligence-based text generators (e.g., Chat GPT) will lead to an even more severe situation when used unreflect by not well experienced rock engineers.

The typical lecture-based teaching practice is ineffective. This passive approach fosters superficial learning instead of a clear understanding of the underlaying principles. Learning from case studies or from real world problems demands reflection and almost always interaction between disciplines. Case studies are also important in dealing with often-ambiguous data to separate opinions from information. Miranda et al. (2020) discuss the merits of project-based learning.

## 4 HOW TO MOTIVATE GENERATION Z FOR ROCK ENGINEERING

The view of the construction and mining industry according to the younger generation is quite vague and unclear. It is true that the presently advertised work-life balance is difficult to achieve with an engineering site in the middle of nowhere. However, the benefits in terms of income and professional satisfaction go along with growing competence gained from lifelong project work with rock masses. Mainstream suggests that mining, and to a certain degree civil engineering as well, are evil so that young people are skeptical to choose that profession (accept that you don’t get likes being a mining or an excavation engineer).

Cruz and Kellam (2018) reported that the main reasons for students to choose engineering are that

- they experienced good performance in math/science courses prior to college
- they played with "building" toys or enjoyed dismantling household objects, acquainted with engineering-based tasks prior to college
- they have the desire for job freedom, creativity, being productive.

Generation Z is according to Moore et al. (2017) used to learn in groups, to survive lots of tests, always online and prefers "gamification" as a teaching tool. Marrying gamification and project-based learning may be a way ahead in motivating students to identify themselves with rock engineering. Recent international developments such as ceasing of supply chains and dependance on certain political unstable regimes along with the increased need for raw materials for the energy transition may raise public acceptance of mining. Initiatives such as RohstoffWissen! (translation: resource knowledge) in Germany may help also.

Barton et al. (2022) discuss ways and means to recruit mining engineering students and conclude that family is influential regarding the choice of profession. They recommend, however, to attract students in freshmen classes by high-quality and engaging material. To this end, the exposure of students to design courses (design of a geological and later to a geotechnical model) appears to be most successful for attracting students.

## 5 CONCLUSION

The authors of this paper have no proven practicable idea how to motivate the youth to be a rock engineer. They guess the best thing to do is during school a work experience week on-site. They know the case of an engineer that took his son for a week to a tunneling project and he was positively surprised.

Due to lack of students, some universities are increasing their contact with and presence in secondary schools by linking with university orientation personnel. By means of talks, presentations and science and technology forums and seminars, it is being possible to attract some students but at a very low pace, which is discouraging. Other potential approaches according to the authors would include mandatory training period in a company.

All in all solutions to attract students to rock engineering would imply an alliance between engineering consultants, construction and mining companies, and authorities to provide on the job experience before and during studies.

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