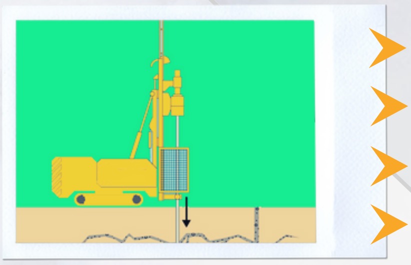
# Full-Day Courses

## COURSE A

## Rock Fractures Grouting



- **Asa Fransson**
- **Akx Malik**
- **Jorge Lopez Molina**
- **Mohamed El Tani**

This Short Course is delivered by the ISRM committee on rock grouting with the following themes: Hydrogeology and grouting, Selecting the grouting pressure, Observation methodology for dam grouting design and Minimal flow criterion and refusal.

### Hydrogeology and grouting

An understanding of your project site is key to climate resilience, sustainable underground structures and related innovation. An integrated approach to tunneling, hydrogeology and grouting (sealing) allows for a description of the geometry, properties and behavior of the system. Grouting data (water loss measurements and grout take) provide guidance to grouting design and monitoring of hydraulic head in boreholes reflects the natural system behavior and the effect of grouting sealing.

### Selecting the grouting pressure

Deciding on grout pressure is an important and preliminary aspect of any grouting scheme. Different schools of thought have different opinions about grouting pressure. We will be discussing the theory behind grouting pressure, various thumb rules on deciding grout pressure, empirical methods, and observational methods used to decide grout pressure w.r.t. rock mass conditions, and project requirements.

### Observation methodology for dam grouting design

Hydrogeological zonation and identification of seepage vulnerable areas, grouting results assessment at different scales and Design adjustments and implementation.

### Minimal flow criterion and refusal

The minimal flow criterion is a stop criterion previously called the refusal criterion. The flow rate limit is the minimal take rate at which grouting is stopped. It will be explained on how to calculate the flow limit when using a suitable grouting model or one of the common models such as Swedish design, RTGC, GIN, amenability theory and Apparent Lugeon.

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**COURSE B**

## Characterizing, Tunnelling (D+B or TBM) and pre-injecting in jointed rock masses. Q, NMT, Qtbm, QH2O, shear strength, joint modelling.

**NICK BARTON**

**TEMPIRICAL METHODS THAT ARE USEFUL IN ROCK ENGINEERING ESPECIALLY FOR TUNNELLING and ROCK SLOPES**

**1. THE NUMEROUS GEO-TECHNICALLY USEFUL LINKS TO Q and the Q-PARAMETERS (PARTS I and II)**

We cannot easily measure the large-scale shear strength and deformability of rock masses, so an empirical method such as 'Q' is a convenient starting point. Q will be compared briefly to RMR. Neither RMR or GSI have sufficient numerical range to be useful 'geotechnical' parameters per se. Q with six orders of magnitude, and Qc with eight orders of magnitude are getting closer to the variability that we often see when tunnelling. Considering the combination of shear strength, deformability, permeability the actual range is huge, and RMR and GSI inevitably cannot follow this.

There are some ultra-simple trends that also demonstrate the viability of the very big Q scale: Δ mm ≈ SPAN(m)/Q, Lugeon L ≈ 1/Q (if no clay), VP ≈ 3.5 + log10Q km/s are three of these. Besides an informal and well-illustrated introduction to each Q- parameter there will be brief demonstrations of the links that have been developed to tunnel and cavern support, to permeability with QH2O, a related discussion of pre-injection needs and success criteria, quantification of over-break (therefore further contrasting NATM and single-shell NMT), shear strength estimation of filled discontinuities, , seismic velocity VP and deformation modulus Emass (both the latter depth-dependent), tunnel and cavern deformation case records, and finally tunnelling cost and time in relation to the full range of Q and tunnel dimensions.

**2. QSLOPE FOR SELECTING STABLE ROCK SLOPE ANGLES NOT NEEDING SUPPORT**

The largest number of rock slopes in the world do not have the benefit of rock reinforcement budgets. They would include hundreds of thousands of access roads to engineering projects like bridges, dams, tunnels, and permanent slopes for hundreds of thousands of roads including many motorways, plus minor rail cuttings and a huge number of building sites.

Of course support is needed when property limits are tight, and rock quality is too low. Support or reinforcement needs can be estimated by other geotechnical methods. QSLOPE specifically addresses the adjustment of slope angles appropriate to the local conditions so that no support is needed. The logarithmic scale of QSLOPE which is largely based on a modified Q-system classification, sees recommended slopes of 45°, 65° and 85° for round-figure QSLOPE values of 0.1, 1 and 10.

The ratings for the first four familiar Q-parameters RQD, Jn, Jr and Ja are unchanged, but the frictional pair Jr/Ja can be applied to both sides of potential wedges with a range of weightings for favourable or unfavourable orientation. Jw and SRF have extended scales and are appropriate to slopes rather than tunnels. There are now more than 500 case records for distinguishing between stable and unstable slopes.

## 3. QTBM FOR TBM PROGNOSIS OF PR, AR AND TIME, AND DELAYS IN FAULTS

TBM Tunnelling in Jointed and Faulted Rock was the 2000 title of a book in which the QTBM prognosis model was developed. A commercial user-friendly program was published by Barton and Abrahão, 2003. The method is based on case record descriptions from approximately 1,000km of TBM tunnelling with 140 well-described cases, mostly open gripper, but now with some notable double-shield, four-machine hard-rock twin-rail tunnels: Guadarrama in Spain and Follobanen in Norway.

The earlier case record data, and a synthesis of all the world records of TBM from 3m to more 12m diameter have an important aspect in common. The ‘popular’ penetration rate PR that is easiest to predict, then advance rate for AR at 24hours (of little practical value), then AR1 week and AR1 month and AR3 months are all declining in a linear manner on a log-log plot of m/hr versus time in hours. This continues out to one or two years. So a project with 10 to 15km of tunnelling per machine may show mean AR of only 0.5m/hr, yet PR may have been 2 or 3m/hr.

This post learning-curve data and the consistent trends of slow-down (actually deceleration) are not popular topics in the commercial tunnelling industry but will be discussed and quantified in this course. Delays in faults are quantifiable if Q-value estimates are available. It is all to do with the deceleration gradient (-m) which is most negative when Q-values are 0.1 or lower. QTBM utilizes Q and several normalized machine-rock parameters, including cutter thrust, rock mass strength and tunnel depth.

# Full-Day Courses

## 4. THE SHEAR STRENGTH OF ROCK, ROCK JOINTS AND ROCK MASSES

This lecture will not follow the popular (modern?) GSI H-B route which has demonstratable problems, but rather look at fundamentals of rock mass behaviour, building from the components: the intact rock, the rock joints, their roughness, the effect of block size and occasional faults.

. The focus will naturally be on discontinuum modelling and also on progressive failure as rock slopes and tunnels do not collapse as with the 'click-of-the-fingers', as incorrectly suggested for so long by the linear Mohr-Coulomb or non-linear (H-B based) 'c plus sigma tan phi'.

There will be a significant section on the Barton-Bandis JRC-based shear strength criterion, on normal and shear stiffness as measured, rather than referenced by modellers from other modellers, so often erroneous. Multi-stage shear testing will be criticized, while the progressive mobilization and degradation of JRC will be emphasized.

Large scale pit slopes can usually be monitored when showing signs of deformation. Progressive failure, or not, may depend on how far the following components are mobilized: CcSs (meaning: crack, crunch, scrape, swoosh) with the major components: failure of intact bridges (C) and shearing along joint planes (S) given capitals. When cohesion breaks it does not have a 'residual' strength: it is the shear strength of the freshly created fractures (c) with their high and unweathered JRC and JCS.

If faulting is involved the lower-strength 'swoosh': the s-component, possibly estimated from tan-1 (Jr/Ja), is the final component. The largest open-pit failures may have significant (s) components as long sections of the final failure may be on planar surfaces, so not matching the assumed 'spoon' shape seen in failing rockfill or soil. Rock masses have to consist of extremely weak rock if behaving as continua. Spoon-shaped failure and 'plastic behaviour' is usually associated with an assumed and erroneous continuum.

TARGET AUDIENCE:
Geologists, engineering geologists, rock mechanics and rock engineering specialists, tunnel designers, open-pit mining advisers, mining engineers with an interest in empirical methods. Post-graduate and post-doctorate level. But few equations.

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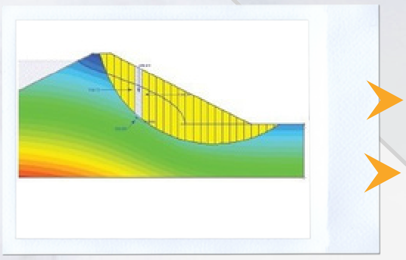
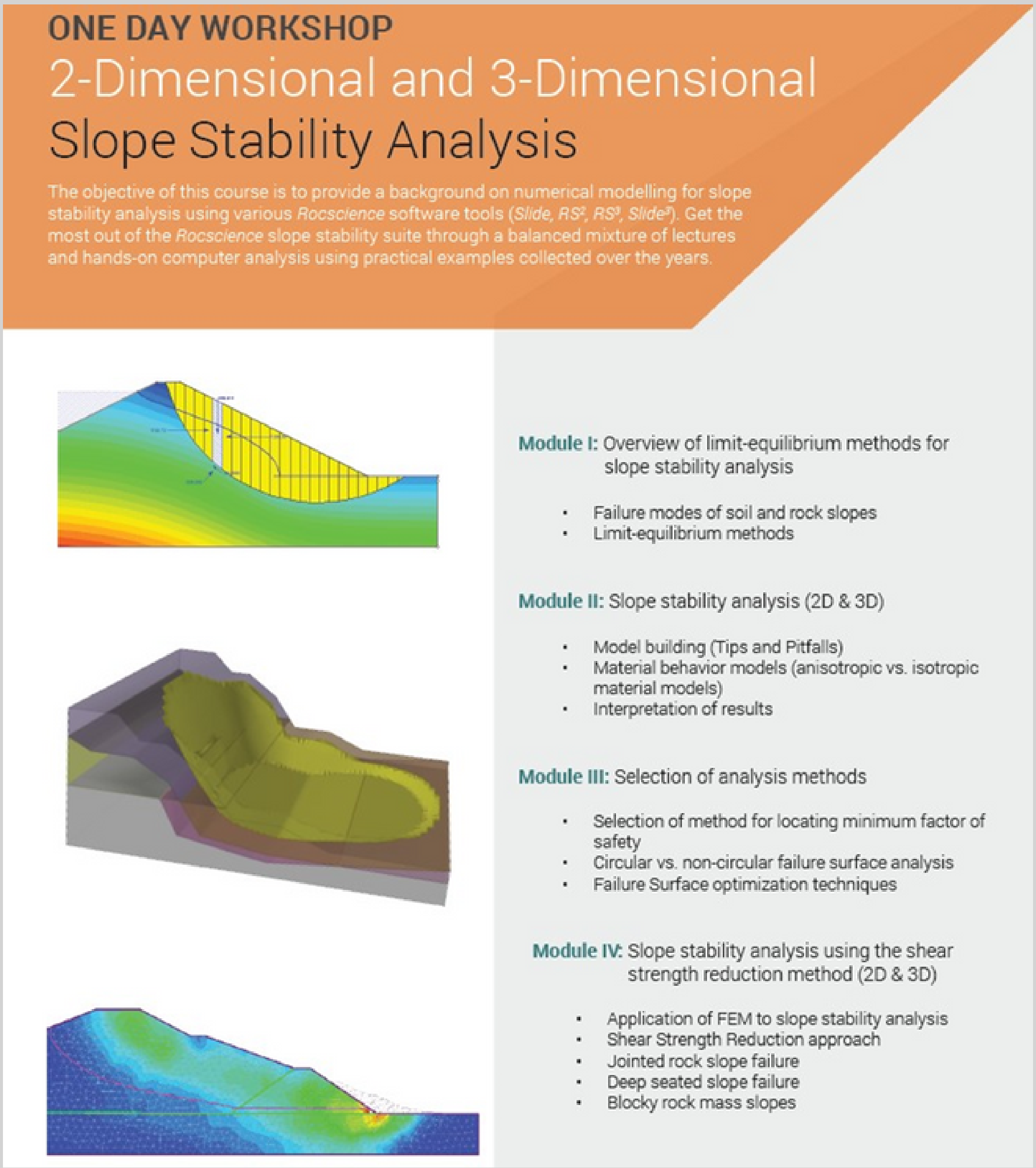
## COURSE C

## 2-Dimensional and 3-Dimensional Slope Stability Analysis



- ROCSCIENCE
- THAMER YACOUB

The objective of this course is to provide a background on numerical modelling for slope stability análisis using various Rocscience software tools (Slde, RS2, RS3, Slide3). Get the mosto ut of the Rocscience slope stability suite through a balanced mixture of lectures and hands-on computer análisis using practical examples collected over the years.



ONE DAY WORKSHOP

2-Dimensional and 3-Dimensional Slope Stability Analysis

The objective of this course is to provide a background on numerical modelling for slope stability analysis using various *Rocscience* software tools (*Slide*, *RS*$^2$, *RS*$^3$, *Slide*$^3$). Get the most out of the *Rocscience* slope stability suite through a balanced mixture of lectures and hands-on computer analysis using practical examples collected over the years.

**Module I:** Overview of limit-equilibrium methods for slope stability analysis

- Failure modes of soil and rock slopes
- Limit-equilibrium methods

**Module II:** Slope stability analysis (2D & 3D)

- Model building (Tips and Pitfalls)
- Material behavior models (anisotropic vs. isotropic material models)
- Interpretation of results

**Module III:** Selection of analysis methods

- Selection of method for locating minimum factor of safety
- Circular vs. non-circular failure surface analysis
- Failure Surface optimization techniques

**Module IV:** Slope stability analysis using the shear strength reduction method (2D & 3D)

- Application of FEM to slope stability analysis
- Shear Strength Reduction approach
- Jointed rock slope failure
- Deep seated slope failure
- Blocky rock mass slopes