Empirical methods, rock mechanics, and structural geological methods useful for excavation in jointed/fractured media

One-Day Short Course

Lecturers:
Dr Nick Barton and Prof. John Cosgrove

2 October 2017 · Cape Town Convention Centre

OBJECTIVES

This one-day short course will cover some key elements of the lecturers' developments and work in rock mechanics, rock engineering and structural geology, respectively. The course will start with the Q-system, an example of observational empiricism, using a key-note treatment of rock mass classification and its many site-interpretation and tunnel-and-cavern design aspects. In the first structural geology lecture, a brief reminder is given of some fundamentals: stress, brittle failure and the factors that determine the fracture spacing, regularity and continuity of fractures within a fracture set, in other words important parts of our input geometries for rock mechanics, modelling, and empiricism. TBM tunnelling performance will follow, from world records to more common performance, especially problems caused by fault zones. The QTBM prognosis method for estimating penetration rate PR and advance rate AR, will also be described and illustrated. The second structural geology lecture will be about the bulk properties of a fractured rock mass, such as connectivity, conductivity and strength. Each is sensitive to the geometry of the fracture network it contains. The non-linear strength of rock, and rock joint characterization and shear strength will be covered next, as these are fundamental to many areas of rock engineering and needed for input to realistic numerical UDEC-BB and 3DEC (jointed) modelling. Fundamentals of rock mass anisotropy, concerning many important properties, including deformability, velocity and permeability, will each be emphasised, to contrast with today's commonly applied isotropic modelling. Non-isotropic and inhomogeneous properties are the rule we must expect.

WHO SHOULD ATTEND

The course content will be of interest to everyone who is involved with rock mechanics and geology:

- engineers
- researchers
- teachers
- students
- professionals.

Dr Nick Barton was educated in the University of London from 1963 to 1970, and has a B.Sc. in civil engineering from King's College, and a Ph.D. on rock slope stability from Imperial College. He worked for two periods in the Norwegian Geotechnical Institute, Oslo, starting in 1971. He was eventually a Division Director, then Technical Advisor, and was also four years in the USA, becoming Manager of Geomechanics in TerraTek, now Schlumberger. Since 2000 he has had his own international rock engineering consultancy, registered as Nick Barton & Associates in Oslo, and also has an office in São Paulo. He has consulted on several hundred projects in a total of 35 countries, and has published widely (300 papers, and two text books, one on TBM tunnelling). He developed the Q-system, which was updated together with Grimstad, and is co-developer of the M-H coupled Barton-Bandis joint behaviour model, coded in UDEC-BB. He has also developed QTBM and more recently Qslope for helping to select maintenance and support-free slope angles for rock cuttings and bench-faces in open pits. He has ten international awards including election as Doctor Honoris Causa (Honorary Doctor) in Argentina. He gave the 6th Mueller Lecture of ISRM, in the Beijing ISRM congress in 2011. He is a Fellow of the ISRM.

John W. Cosgrove is a Professor in the Department of Earth Sciences and Engineering, Imperial College London, UK. He won the Paul Fourmarier Gold Medal, awarded by the Royal Academy of Belgium in 2005 for work on fluid induced failure and has received awards for excellence in teaching from Imperial College. He was responsible for the Masters course in Structural Geology and Rock Mechanics for many years. His co-authored book (Price N.J. & Cosgrove J.W. 1990 'Analysis of Geological Structures') has been used worldwide and he has recently co-authored with John Hudson a book on the link between rock engineering and structural geology (Cosgrove J.W. and Hudson J.A. 'Structural Geology and Rock Engineering'). He has worked extensively in consulting activities for rock mechanics and rock engineering projects.

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1. FORTY YEARS WITH THE Q-SYSTEM: LESSONS AND DEVELOPMENTS (N. Barton)

The lecture will describe the background, motivation, and special characteristics of the six Q-parameters, and show how to estimate overbreak with Jn/Jr. Joint or fracture characteristics are fundamental. Q-histograms to speed logging of core, for logging of exposures, and for logging tunnel-advance will be demonstrated. The Q-system is specifically geared to single-shell B+S(fr), and tunnel support selection using NMT, as in a pre-injected high-speed rail tunnel, and in a 60 m span cavern. These will be contrasted to double-shell and more expensive NATM methods. Use of the Q-system for estimating temporary support for those who nevertheless choose NATM, and more robust alternatives to steel sets (RRS arches for bad ground) will be emphasised. Pre-injection will also be mentioned, as the joint or fracture characteristics of Q can be improved. Cost and time for tunnelling versus Q-value, and the empirical estimation of depth-dependent deformation, deformation modulus, and Q from P-wave velocity, will each be presented and discussed.

2. THE GENERATION OF FRACTURE NETWORKS IN A ROCK MASS USING FRACTURE ANALYSIS (J. Cosgrove)

Rock engineering projects, including those involving surface excavations and/or tunnelling, are almost invariably situated in fractured rock masses. Obviously the fracture network often dominates the bulk mechanical properties of the rock mass. These networks are built up by the superposition of individual fracture sets each linked to a particular geological process (burial, tectonism, exhumation). Understanding the relationship between the stress and the fractures it can generate, and the interaction of the regional stress field with fractures already formed within the rock mass, provides a basis for Fracture Analysis, which is a technique that enables the chronology of the fracture sets in the network to be determined and the stress history of the region over geological time to be established. This knowledge is important to the rock engineer as the order of superposition of the individual fracture sets making up the network has a first order impact on the geometry of the network, and therefore on its properties.

3. TBM PERFORMANCE, PROGNOSIS, AND RISK CAUSED BY FAULTING (N. Barton)

This lecture includes an analysis of 1000 km of open-gripper TBM tunnels in jointed and faulted rock, and a much smaller number of double-shield, and also a record EPB. Each and everyone give evidence of a general deceleration as the tunnel gets longer, obviously following the speed-up of PR and AR during the 'learning-curve' period. Deceleration is also exhibited by the remarkable TBM world records from 3m up to more than 12m diameter. Utilization is very much a rock quality and time-dependent variable, and a '600m per month' prognosis for a whole tunnel always needs to be questioned. Particular attention is directed towards the delaying effect of fault zones, and their quantification by a simple equation. Choice of TBM for long and deep tunnels is analysed and also questioned, as a hybrid solution may sometimes be superior and involve less risk. It may be better to choose this option instead of being forced into it by adverse circumstances, even by fatalities in some deep mountain tunnels.

4. THE ROLE OF THE FRACTURE NETWORK IN CONTROLLING THE BULK PROPERTIES OF A FRACTURED ROCK MASS (J. Cosgrove)

The bulk properties of a fractured rock mass (connectivity, conductivity, strength etc.) are sensitive to the geometry of the fracture network it contains. This geometry is determined by the order in which the various fracture sets making up the network are superimposed. Fracture analysis enables this chronology to be determined and thus the likely bulk properties of the rock mass to be established. Knowledge of the geological evolution of a region allows the likely fracture network to be determined and its impact on rock stability to be predicted. This is illustrated using an example where the stability of a fractured rock mass acting as an abutment to a bridge is predicted from the geological history and then tested against on-site observations. A reminder of residual stress and its role in the formation of exfoliation fractures and how these fractures can impact on both surface and underground excavations, is also included.

5. SHEAR STRENGTH OF ROCK, ROCK JOINTS AND ROCK MASSES: PROBLEMS AND SOLUTIONS (N. Barton)

The contribution of a non-linear, non-Mohr-Coulomb, non-Hoek-Brown shear strength of the intact rock is a starting point for this three-part lecture. The development of the JRC-JCS model for characterizing rock joints, and the scale-effect adjustment by block size is then demonstrated. Simple index tests to obtain roughness and wall-strength input data are explained. The shear strength of rock masses actually cannot be described accurately by linear Mohr-Coulomb or non-linear Hoek-Brown, because the process of rock mass failure is block-size dependent and intact bridge dependent. The latter fail at small strain, and the resulting fresh fractures, followed by the rock joints, followed by the clay-filled discontinuities, provide a progressive cascade of shear resistance. These process-and-strain dependent components are usually non-linear. Therefore 'c then tan ϕ' is more correct than the conventional 'c plus tanϕ' if continuum modelling is needed due to the scale of the problem. There are possibilities to estimate 'c' and 'ϕ' from the cohesive and frictional strength components CC and FC which are hidden in the formula for Qc.

6. ANISOTROPY IS EVERYWHERE: TO SEE, TO MEASURE, TO MODEL (N. Barton)

Most properties of rock masses are actually anisotropic due to geologic origin and tectonic history, as we have seen from structural geological theory and practice. Some further illustrative examples will be shown, and contrasted with isotropic continuum assumptions. Anisotropy is most common due to joint stiffness contrasts (normal contra shear), and due to a commonly experienced stress anisotropy, so that both deformability anisotropy and seismic anisotropy are then automatic. The strongest anisotropy is reserved for permeability, as demonstrated with 3D multiple-borehole permeability measurements. Permeability tensors rotate and reduce in magnitude after grouting, due to the initially greater anisotropic permeability, which can be orders of magnitude.

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