Society for Rock Mechanics
& Engineering Geology
(Singapore)

A Professional
Developmental Course

Rock Mechanics and Empirical Methods in Rock Engineering

conducted by Dr. Nick Barton / 3-4 Sept 2014 / Singapore

Course Overview

This two-days short course will cover some key elements of the lecturer's internationally applied developments in rock mechanics and rock engineering. The course will start with a thorough treatment of the Q-system of rock mass classification and its many site-interpretation and tunnel-design aspects. This system was developed mostly from hydropower-related tunnels and caverns, but now has numerous transport tunnels (road and rail) as part of the 2000 plus case records.

Extensive work in TBM tunneling, with the Q_{TBM} prognosis method for estimating penetration rate PR and actual advance rate AR, will also be described, and illustrated by many case records, including hydropower tunnel cases, and the effects of high rock cover on rock mass failure, its unconventional modeling, and problems with fault zones, water and high stress, with interpretation through Q_{TBM}

International experiences will be reflected in numerous case record examples, from hydropower projects and from metro projects, including a dramatic cavern collapse. Rock mass *Q-system* application, and rock joint characterization techniques for site investigation, for preliminary support design of diversion tunnels and large caverns, and for follow-up and support modification during construction will each be described. The links between Q and seismic velocity will be explained. Mapping techniques, core logging interpretation, and so-called 'histogram-logging' will be emphasized.

Rockmass improvement techniques for jointed rock masses, using pre-injection will be quantified. Fundamentals of rock joint characterization will be covered as these are fundamental to many areas of rock engineering and numerical modelling. Most recently the shear strength of rock masses has also been linked to Q, and modelling using 'c then tan ϕ' degradation /mobilization is suggested as a more realistic method than conventional Mohr-Coulomb or Hoek-Brown / GSI practice.

Q and Qc (= Q x UCS/100) provide estimates of tunnel and cavern support, support pressure, deformation modulus, vertical and horizontal deformation in tunnels/caverns, P-wave velocity (and vice versa), Lugeon value (ball-park estimate for clay-free rock: see also more general Q_{H2O}), and CC and FC (cohesive component and frictional component) in case continuum modelling is unavoidable.

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Day 1:

09.00-11.00 ***1. INTRODUCING Q-SYSTEM OF ROCK MASS CHARACTERIZATION***

Background, motivation, characteristics of Q. The six Q-parameters explained with numerous examples, including Q-roughness Jr-parameter links to the more sophisticated JRC. Q-histogram logging. Q-Tables and general logging advice. Also Q-RMR comparison.

TEA BREAK / QUESTIONS

11.30-13.00 ***2. LINKING Q TO USEFUL PARAMETERS FOR DESIGN***

Core logging examples, including faulted and weathered rock. Rock mass strength estimation from Q (CC and FC). P-wave velocity, and effects of weathering and depth on velocity, and the links to Q. The Q-based estimation of permeability for clay-free and clay-bearing rock masses, the latter with Q modified. Deformation modulus estimation at depth, from seismic velocity or from Q, for dam-site characterization. Tunnel and cavern convergence estimation, from empirical Q formulae.

LUNCH BREAK

14.00-15.00 ***3. TUNNEL SUPPORT SELECTION FROM Q CLASSIFICATION, AND SUPPORT ELEMENT PROPERTIES***

Historical development of Q for B+S(mr) mesh-based support. NMT tunnel support philosophy, as applies in diversion tunnels and access tunnels. Tunnel support design with B+S(fr) fibre-reinforced shotcrete support. Temporary or permanent support. Physical performance of S(fr) and bolting. Reinforced RRS arches for bad ground. Cost versus Q and tunnel size.

TEA BREAK / QUESTIONS

15.30-16.30 ***4. PRE-GROUTING AND WATER CONTROL***

Water control methods in tunnels. Simplified interpretation of Lugeon tests for pre-injection grout design. Comparing joint aperture estimates with available grout-particle sizes. High-pressure injection concepts and pressure decline. Some performance and volumetric data from pre-injected tunnels. Rock quality improvement from Q-parameter improvement, by high-pressure pre-injection.

DISCUSSION AND QUESTIONS 16.30 - 17.00

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Day 2 :

09.00-10.30 ***5. TBM PERFORMANCE AND PROGNOSES***

Fundamentals of cutter action, rock breakage and cutter wear. Penetration rate, advance rate and aspects of time and utilization. Case record analysis and geological reasons for deceleration. Performance with open gripper and double-shield machines. The Q_{tbm} model of performance prognosis. Examples of Q_{tbm} application from Chile, Brazil, Spain, Norway.

TEA BREAK / QUESTIONS

11.00-12.30 ***6. RISK TO TBM TUNNELLING FROM FAULTS AND HIGH STRESS***

Long tunnels and TBM. Interpretation of TBM difficulties in terms of Q_{tbm} model. The concept of ‘multiple unexpected events’. TBM tunnelling difficulties, with examples from Italy, Kashmir, Taiwan, Chile, China, Peru. Stress-strength and rock failure problems. Use of probe drilling and pre-grouting in Hong Kong sewage tunnel.

LUNCH BREAK

13.30-15.00 **7. *ANISOTROPY IS EVERYWHERE – TO SEE AND TO MEASURE***

This one hour lecture was given to introduce the subject of anisotropy at an international workshop in 2013. Richly illustrated examples are given from geology, rock mechanics and rock joint behaviour, stress measurement, seismic anisotropy, hydro-geology and permeability, with illustration from rock engineering projects from several countries. The widespread presence of anisotropic behaviour stands in strong contrast to today’s pre-occupation with colourful isotropic continuum modelling.

TEA BREAK / QUESTIONS

15.30-16.30 ***7. LESSONS FROM A SHALLOW METRO CAVERN COLLAPSE***

A metro-station cavern collapsed suddenly during construction, causing the death of seven people. Numerous boreholes had indicated 3 to 4 m of rock cover beneath 16-18 m of sand, soil and saprolite. Heavy structural support was therefore used as temporary support, instead of rock bolts and shotcrete. The combination of ‘unexpected events’ combined to cause an unprecedented accident, which was ‘unpredictable in the circumstances’. The risks involved with (too) shallow metro-line and metro-station design are emphasised.

16.30-17.00 *8. INVESTIGATIONS AND DESIGN OF THE LARGEST CAVERN EVER BUILT FOR PUBLIC USE*

The largest cavern ever built for use by the public, effectively doubling the previous largest span, was built in jointed gneiss in Norway, for initial use in the 1994 Winter Olympic Games. Q-logging site investigation, cross-hole tomography, stress measurement and numerical UDEC-BB modelling and NMT-style permanent support design for this 62 m span cavern are described, including follow-up mapping and monitoring. The 'Class A' predictions of performance proved to be very accurate.

DISCUSSION AND QUESTIONS 17.00 – 17.30

Optional Day 3 (half-day)

09.00-12.00 9. FIELD LOGGING PRACTICE: DRILL-CORE, TUNNEL (OR QUARRY) SITE Q-histogram LOGGING

The best way to 'interrogate' a rock mass so that its engineering quality can be assessed in a quantitative way, is to perform Q-histogram logging. This utilizes a logging sheet where all six Q-parameters, their ratings, and brief descriptions are given in a compact 1-page format, with space/rectangles for recording tens, hundreds, even thousands of observations. An EXCEL program subsequently calculates the statistics. Most frequent observations/ratings, e.g. 95/9 x 1.5/2 x 0.66/2.5 are found immediately. This can be performed using core, observing rock in tunnels, or along quarry benches.

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