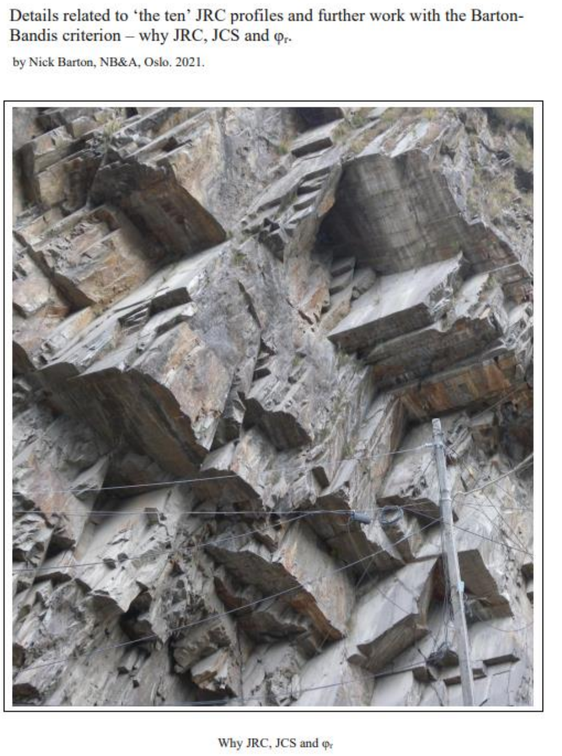
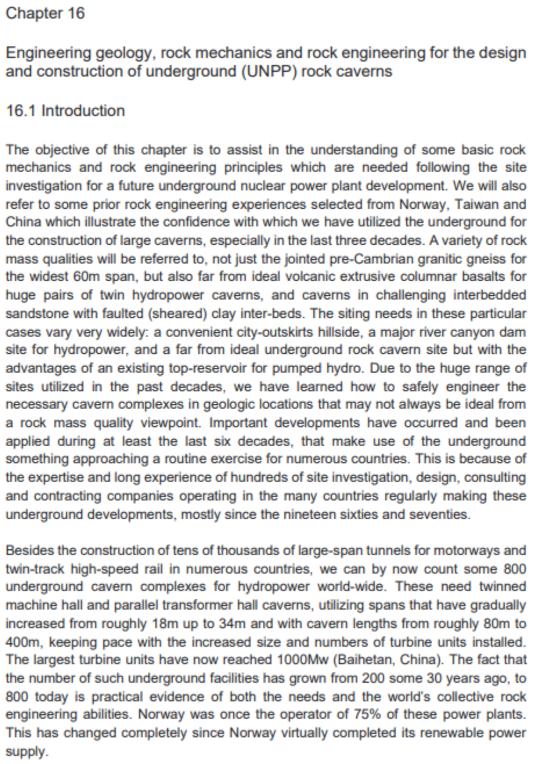


Details related to 'the ten' JRC profiles and further work with the Barton-Bandis criterion – why JRC, JCS and φ_r.

by Nick Barton, NB&A, Oslo. 2021.

Why JRC, JCS and φ_r

2021



Chapter 16

Engineering geology, rock mechanics and rock engineering for the design and construction of underground (UNPP) rock caverns

16.1 Introduction

The objective of this chapter is to assist in the understanding of some basic rock mechanics and rock engineering principles which are needed following the site investigation for a future underground nuclear power plant development. We will also refer to some prior rock engineering experiences selected from Norway, Taiwan and China which illustrate the confidence with which we have utilized the underground for the construction of large caverns, especially in the last three decades. A variety of rock mass qualities will be referred to, not just the jointed pre-Cambrian granitic gneiss for the widest 60m span, but also far from ideal volcanic extrusive columnar basalts for huge pairs of twin hydropower caverns, and caverns in challenging interbedded sandstone with faulted (sheared) clay inter-beds. The siting needs in these particular cases vary very widely: a convenient city-outskirts hillside, a major river canyon dam site for hydropower, and a far from ideal underground rock cavern site but with the advantages of an existing top-reservoir for pumped hydro. Due to the huge range of sites utilized in the past decades, we have learned how to safely engineer the necessary cavern complexes in geologic locations that may not always be ideal from a rock mass quality viewpoint. Important developments have occurred and been applied during at least the last six decades, that make use of the underground something approaching a routine exercise for numerous countries. This is because of the expertise and long experience of hundreds of site investigation, design, consulting and contracting companies operating in the many countries regularly making these underground developments, mostly since the nineteen sixties and seventies.

Besides the construction of tens of thousands of large-span tunnels for motorways and twin-track high-speed rail in numerous countries, we can by now count some 800 underground cavern complexes for hydropower world-wide. These need twinned machine hall and parallel transformer hall caverns, utilizing spans that have gradually increased from roughly 18m up to 34m and with cavern lengths from roughly 80m to 400m, keeping pace with the increased size and numbers of turbine units installed. The largest turbine units have now reached 1000Mw (Baihetan, China). The fact that the number of such underground facilities has grown from 200 some 30 years ago, to 800 today is practical evidence of both the needs and the world's collective rock engineering abilities. Norway was once the operator of 75% of these power plants. This has changed completely since Norway virtually completed its renewable power supply.

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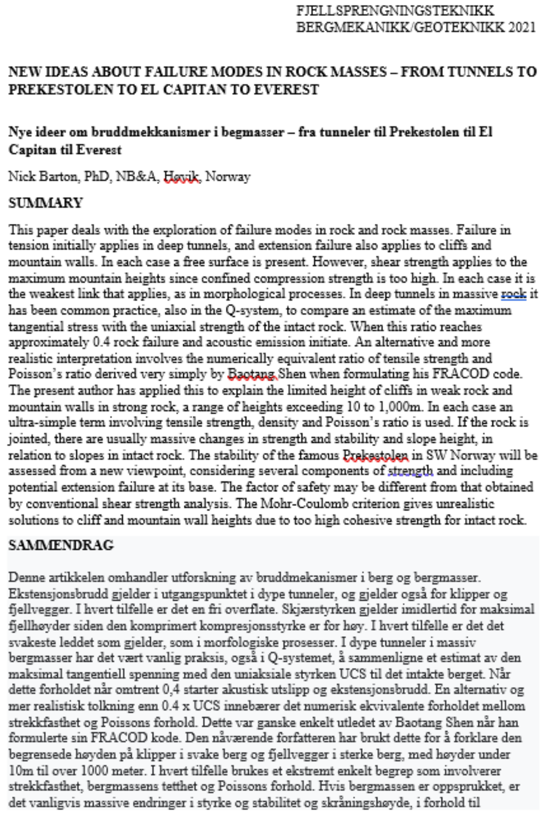

FJELLSPRENGNINGSTEKNIKK
BERGMEKANIKK/GEOTEKNIKK 2021

NEW IDEAS ABOUT FAILURE MODES IN ROCK MASSES – FROM TUNNELS TO PREKESTOLEN TO EL CAPITAN TO EVEREST

Nye ideer om bruddmekkanismer i begmasser – fra tunneler til Prekestolen til El Capitan til Everest

Nick Barton, PhD, NB&A, Høvik, Norway

SUMMARY

This paper deals with the exploration of failure modes in rock and rock masses. Failure in tension initially applies in deep tunnels, and extension failure also applies to cliffs and mountain walls. In each case a free surface is present. However, shear strength applies to the maximum mountain heights since confined compression strength is too high. In each case it is the weakest link that applies, as in morphological processes. In deep tunnels in massive rock it has been common practice, also in the Q-system, to compare an estimate of the maximum tangential stress with the uniaxial strength of the intact rock. When this ratio reaches approximately 0.4 rock failure and acoustic emission initiate. An alternative and more realistic interpretation involves the numerically equivalent ratio of tensile strength and Poisson's ratio derived very simply by Baotang Shen when formulating his FRACOD code. The present author has applied this to explain the limited height of cliffs in weak rock and mountain walls in strong rock, a range of heights exceeding 10 to 1,000m. In each case an ultra-simple term involving tensile strength, density and Poisson's ratio is used. If the rock is jointed, there are usually massive changes in strength and stability and slope height, in relation to slopes in intact rock. The stability of the famous Prekestolen in SW Norway will be assessed from a new viewpoint, considering several components of strength and including potential extension failure at its base. The factor of safety may be different from that obtained by conventional shear strength analysis. The Mohr-Coulomb criterion gives unrealistic solutions to cliff and mountain wall heights due to too high cohesive strength for intact rock.

SAMMENDRAG

Denne artikkelen omhandler utforskning av bruddmekanismer i berg og bergmasser. Ekstensjonsbrudd gjelder i utgangspunktet i dype tunneler, og gjelder også for klipper og fjellvegger. I hvert tilfelle er det en fri overflate. Skjærstyrken gjelder imidlertid for maksimal fjellhøyder siden den komprimert kompresjonsstyrke er for høy. I hvert tilfelle er det det svakeste leddet som gjelder, som i morfologiske prosesser. I dype tunneler i massiv bergmasser har det vært vanlig praksis, også i Q-systemet, å sammenligne et estimat av den maksimal tangentiell spenning med den uniaksiale styrken UCS til det intakte berget. Når dette forholdet når omtrent 0,4 starter akustisk utslipp og ekstensjonsbrudd. En alternativ og mer realistisk tolkning enn 0.4 x UCS innebærer det numerisk ekvivalente forholdet mellom strekkfasthet og Poissons forhold. Dette var ganske enkelt utledet av Baotang Shen når han formulerte sin FRACOD kode. Den nåværende forfatteren har brukt dette for å forklare den begrensede høyden på klipper i svake berg og fjellvegger i sterke berg, med høyder under 10m til over 1000 meter. I hvert tilfelle brukes et ekstremt enkelt begrep som involverer strekkfasthet, bergmassens tetthet og Poissons forhold. Hvis bergmassen er oppsprukket, er det vanligvis massive endringer i styrke og stabilitet og skråningshøyde, i forhold til

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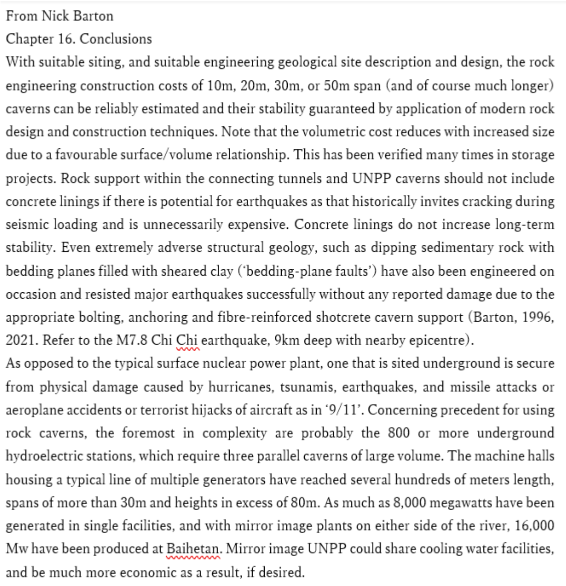

From Nick Barton
Chapter 16. Conclusions

With suitable siting, and suitable engineering geological site description and design, the rock engineering construction costs of 10m, 20m, 30m, or 50m span (and of course much longer) caverns can be reliably estimated and their stability guaranteed by application of modern rock design and construction techniques. Note that the volumetric cost reduces with increased size due to a favourable surface/volume relationship. This has been verified many times in storage projects. Rock support within the connecting tunnels and UNPP caverns should not include concrete linings if there is potential for earthquakes as that historically invites cracking during seismic loading and is unnecessarily expensive. Concrete linings do not increase long-term stability. Even extremely adverse structural geology, such as dipping sedimentary rock with bedding planes filled with sheared clay ('bedding-plane faults') have also been engineered on occasion and resisted major earthquakes successfully without any reported damage due to the appropriate bolting, anchoring and fibre-reinforced shotcrete cavern support (Barton, 1996, 2021. Refer to the M7.8 Chi Chi earthquake, 9km deep with nearby epicentre).

As opposed to the typical surface nuclear power plant, one that is sited underground is secure from physical damage caused by hurricanes, tsunamis, earthquakes, and missile attacks or aeroplane accidents or terrorist hijacks of aircraft as in '9/11'. Concerning precedent for using rock caverns, the foremost in complexity are probably the 800 or more underground hydroelectric stations, which require three parallel caverns of large volume. The machine halls housing a typical line of multiple generators have reached several hundreds of meters length, spans of more than 30m and heights in excess of 80m. As much as 8,000 megawatts have been generated in single facilities, and with mirror image plants on either side of the river, 16,000 Mw have been produced at Baihetan. Mirror image UNPP could share cooling water facilities, and be much more economic as a result, if desired.

2021

5º CONGRESSO BRASILEIRO DE TÚNEIS E ESTRUTURAS SUBTERRÂNEAS
SEMINÁRIO INTERNACIONAL "LATIN AMERICAN TUNNELLING SEMINAR – LAT 2021"

TECHNICAL DETAILS OF SINGLE-SHELL NMT TUNNELS

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E. Quadros
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Abstract: Selected aspects of NMT are described in some detail. Tunnelling in jointed rock that may be clay-bearing and faulted is assumed, with a typical wide range of Q of at least 100 down to 0.01, or roughly RMR = 80 down to 20, but not needing double-shell NATM. Selected aspects to be discussed will be the three principle EDZ, two of them representing the load-bearing cylinder of rock where redistribution of principal stresses and joint deformation occurs, the third the disturbance due to blasting, which is much narrower. So-called 'plastic' behaviour via GSI, H-B, RS2 modelling is rejected since based on too many assumptions and complex page-wide equations. Case records suggest that combinations of bolting and fiber-reinforced shotcrete can provide stable tunnels at reasonable cost, but if some aspects are neglected, like under-dimensioned shotcrete thickness, lack of washing prior to shotcreting, and failure to record the presence of clay, then surprises can occur. Two important further conventions need to be adhered to. The Q-system based B+S(fr) reinforcement and support recommendation was never designed to accommodate or rely on lattice girders, which are far too 'soft' since unbolted and unevenly loaded. Single-shell Q-based tunnel design was also never intended to allow the passage of water at high velocities, such as 10m/s river diversion compared to the case-record expected 2m/s of typical headrace and pressure tunnels. When rock mass quality is compromised by fracture zones, or if permeability is too high and inflow from the surrounding rock mass needs prevention for ensuring both dry in-tunnel and stable external environments, then systematic pre-injection may be demanded. Injection of suitable stable grouts at high pressure improves the rock mass quality Q, and over-design of unadjusted Q-based support is then apparent. P-wave velocities, and deformation moduli are also improved by pre-grouting, as verified in formal dam-site studies in Brazil and Iran. In reality millions of kilometers of grout holes beneath the world's largest dams are giving the same evidence. Suitable stable grouts with their extensional viscocity must not be disqualified with filter-pumps. High injection pressures are needed, but do not hold pressure when flow ceases. Wet shotcrete, leaking bolt holes, and the need for post-injection indicate failed technology, if the objective was to pre-inject in one round only and prevent environmental damage.

1 INTRODUCTION

The frequent assumption of those who feel they know best is that the Q-system only applies to typical hard jointed rocks. We actually make wider use of Q in NMT: the Norwegian Method of (single-shell) Tunnelling. The original case records included 50 different rock types in the initial two hundred or so cases analysed, with deliberate choice of challenging cases such as clay-bearing and sheared rock masses so that significant amounts of support were included. If a more limited range of application of Q had been suggested that would have been the result, since Q is an *a posteriori* empirical method.

Development of the Q-system has meant engagement in numerous tunnel and cavern projects in Norway and abroad since 1975, including experiences in water transfer tunnels, hydropower headrace and pressure tunnels in many countries. Significantly, the Q-system data base and applicability was greatly expanded in 1993, by Grimstad's incorporation of steel fiber reinforced shotcrete S(fr) and by the development of corrosion-protected sleeved (CT) bolts. Both have added to the reliability of B+S(fr) single-shell permanent support. The Q-system has been successfully used in rocks with UCS as low as 4 to 7MPa (significantly jointed chalk marl in shallower parts of the Channel Tunnel: Barton and Warren, 2019) and UCS up to at least 300MPa for some granites, gneisses and quartzites.

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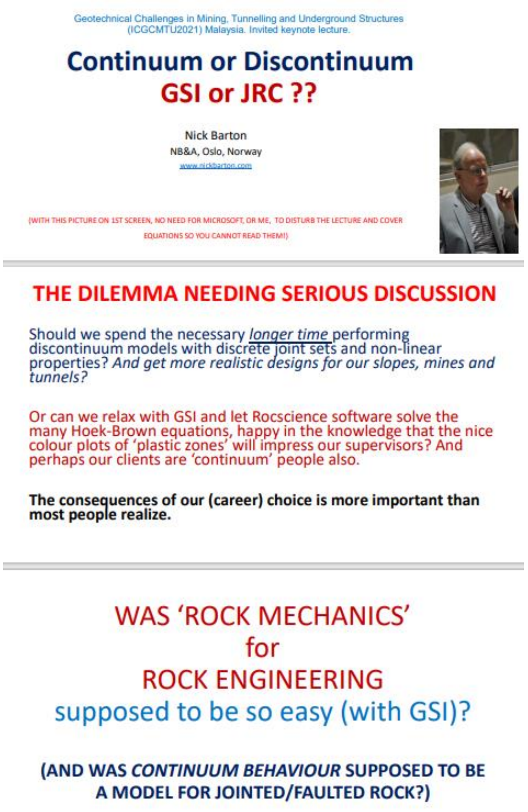

Geotechnical Challenges in Mining, Tunnelling and Underground Structures
(ICGCMTU2021) Malaysia. Invited keynote lecture.

Continuum or Discontinuum
GSI or JRC ??

Nick Barton
NB&A, Oslo, Norway
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(WITH THIS PICTURE ON 1ST SCREEN, NO NEED FOR MICROSOFT, OR ME, TO DISTURB THE LECTURE AND COVER EQUATIONS SO YOU CANNOT READ THEM!)

THE DILEMMA NEEDING SERIOUS DISCUSSION

Should we spend the necessary *longer time* performing discontinuum models with discrete joint sets and non-linear properties? *And get more realistic designs for our slopes, mines and tunnels?*

Or can we relax with GSI and let Rocscience software solve the many Hoek-Brown equations, happy in the knowledge that the nice colour plots of 'plastic zones' will impress our supervisors? And perhaps our clients are 'continuum' people also.

The consequences of our (career) choice is more important than most people realize.

WAS 'ROCK MECHANICS' for ROCK ENGINEERING supposed to be so easy (with GSI)?

(AND WAS *CONTINUUM BEHAVIOUR* SUPPOSED TO BE A MODEL FOR JOINTED/FAULTED ROCK?)

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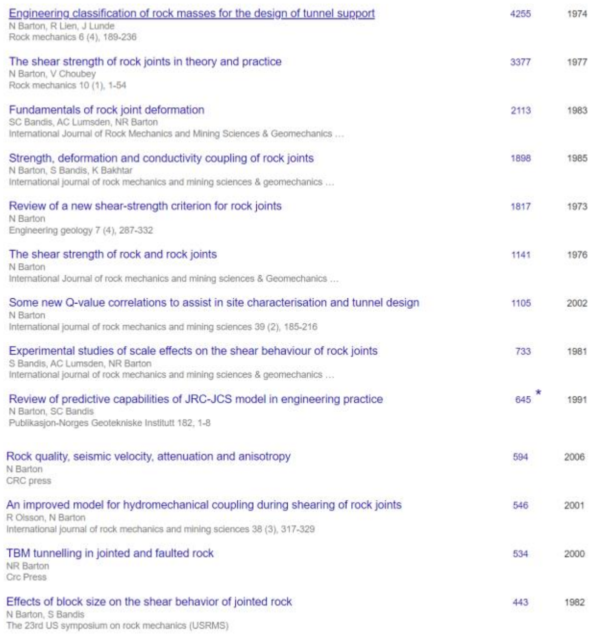

Engineering classification of rock masses for the design of tunnel support N Barton, R Lien, J Lunde Rock mechanics 6 (4), 189-236	4255	1974
The shear strength of rock joints in theory and practice N Barton, V Choubey Rock mechanics 10 (1), 1-54	3377	1977
Fundamentals of rock joint deformation SC Bandis, AC Lumsden, NR Barton International Journal of Rock Mechanics and Mining Sciences & Geomechanics ...	2113	1983
Strength, deformation and conductivity coupling of rock joints N Barton, S Bandis, K Bakhtar International journal of rock mechanics and mining sciences & geomechanics ...	1898	1985
Review of a new shear-strength criterion for rock joints N Barton Engineering geology 7 (4), 287-332	1817	1973
The shear strength of rock and rock joints N Barton International Journal of rock mechanics and mining sciences & Geomechanics ...	1141	1976
Some new Q-value correlations to assist in site characterisation and tunnel design N Barton International journal of rock mechanics and mining sciences 39 (2), 185-216	1105	2002
Experimental studies of scale effects on the shear behaviour of rock joints S Bandis, AC Lumsden, NR Barton International journal of rock mechanics and mining sciences & geomechanics ...	733	1981
Review of predictive capabilities of JRC-JCS model in engineering practice N Barton, SC Bandis Publikasjon-Norges Geotekniske Institutt 182, 1-8	645 *	1991
Rock quality, seismic velocity, attenuation and anisotropy N Barton CRC press	594	2006
An improved model for hydromechanical coupling during shearing of rock joints R Olsson, N Barton International journal of rock mechanics and mining sciences 38 (3), 317-329	546	2001
TBM tunnelling in jointed and faulted rock NR Barton Crc Press	534	2000
Effects of block size on the shear behavior of jointed rock N Barton, S Bandis The 23rd US symposium on rock mechanics (USRMS)	443	1982

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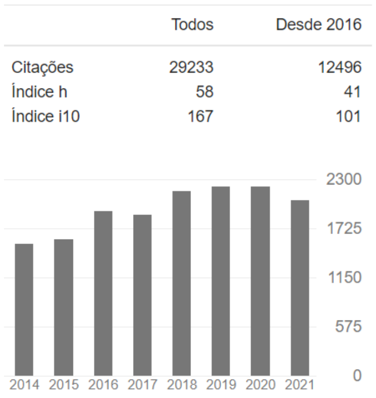

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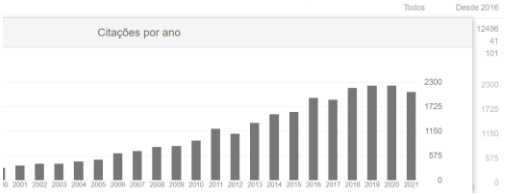

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