

## Dr. Nick Barton's interview

Zagreb, 02.06.2011



Nick Barton



Ivan Vrkljan

Dr. Nick Barton was interviewed by Prof. Ivan Vrkljan during Dr. Barton's stay in Croatia from 1 to 6 June 2011. Dr. Barton came to Zagreb to hold a short course entitled "Rock Engineering for Tunnels (Drill-and-Blast and TBM), Pre-Grouting, Caverns, Dam Abutments, Rock Slopes and Rockfill". The course was organized by the Croatian Geotechnical Society (CGS) and the event was hosted by the Faculty of Mining, Geology and Petroleum Engineering of the University of Zagreb. Dr. Barton also gave the 10<sup>th</sup> Nonveiller Lecture entitled: "Pre-Grouting for Water Control and for Rock Mass Property Improvement". Nonveiller Lectures are organized by the Croatian Geotechnical Society in honour and memory of professor Ervin Nonveiller. On the occasion of this lecture, CGS awarded the plaque of recognition to Dr. Barton in deep appreciation of the scientific and professional support given to the Croatian Geotechnical Society. Ivan Vrkljan is a Full Professor for the Engineering Rock Mechanics at the Faculty of Civil Engineering of the University of Rijeka, and the Head of Geotechnical Laboratory at the Institut IGH in Zagreb. He is also the Secretary General of the Croatian Geotechnical Society.

### **Brief information about Nicholas R. BARTON**

*Dr. Nick Barton was educated at the University of London from 1963 to 1970 and has a B.Sc. degree in civil engineering from King's College, and a Ph.D. degree on rock slope stability from Imperial College.*

*One of Dr. Barton's principal contributions to rock mechanics is his work related to discontinuities in the rock mass. In the course of 1972, while he conducted research work at the Norwegian Geotechnical Institute, he developed the peak shear strength criterion for rock joints, which had already been presented in his Ph.D. thesis on Rock Mechanics defended in 1971 at the London's Imperial College. He introduced a modification of this criterion in 1976 (basic frictional angle was replaced by residual frictional angle  $\phi_r$ ), and in 1978 (mobilization and degradation of joint roughness JRC with displacement). He also introduced the Barton-Bandis Model linking deformation, dilation and aperture. In 1985 the Barton-Bandis model was installed as a subroutine in the Cundall's remarkable UDEC code, in form of UDEC-BB.*

*Dr. Barton developed the well known Q system for rock classification which is used in the design of support systems, both in tunnels and in large underground caverns. The Q system is also used for rock mass characterization. Dr. Barton linked his classification (Q value) with the deformations in tunnels and caverns, and with rock mass deformability modulus. These relations were improved in 1995 when he found out that the parameter  $Q_c$  (Q normalised by compressive strength different from 100 MPa) correlates well with seismic velocities and deformability moduli.*

*In 1999 Barton developed the QTBM method for predicting TBM single-shield and double-shield performance in jointed and faulted rock, and for estimating TBM tunnel rock reinforcement and support needs.*

*In 1994 and since then he has actively promoted the Norwegian Method of Tunnelling (NMT) with the Q system for support selection, as a viable single-shell alternative for permanent tunnel support in countries outside Norway. This is an alternative to double-shell methods including inter alia the New Austrian Tunnelling Method (NATM), at least when rock mass conditions are 'normal' (poor, fair, good etc).*

*His academic activities include the posts of Adjunct Professor, Dept. of Mining, University of Utah (1983-1984); Adjunct Professor, Dept. of Rock Mechanics, University of Lulea (1985-1989); Visiting Professor, Sao Paulo University (1997-2001).*

*Dr. Barton has 40 years of working experience on various rock engineering projects mostly in the field of civil engineering. He has consulted on projects in 34 countries.*

*He has seven international awards including the 8<sup>th</sup> Laurits Bjerum Memorial Lecture in Oslo, 1985, and the 4<sup>th</sup> Manuel Rocha Memorial Lecture in Lisbon, 1987. In 2004, he was awarded the honorary degree as Doctor Honoris Causa by the University of Cordoba, Argentina. He was the coordinator of the ISRM Working Group (Suggested methods for quantitative description of discontinuities in rock masses (1974-1980).*

*He has published 260 papers and two textbooks: „TBM Tunnelling in Jointed and Faulted Rock“, 2000 (Balkema) and "Rock Quality, Seismic Velocity, Attenuation and Anisotropy", 2006 (Taylor and Francis).*

*Since 2001 he has had his own international rock engineering consultancy, registered as Nick Barton & Associates in Oslo, and also has an office in Sao Paulo.*

*Recently Dr. Barton was selected for the 6<sup>th</sup> Müller Award of ISRM. This award honours the memory of Professor Leopold Müller, the founder of the ISRM (International Society of Rock Mechanics) and is bestowed in recognition of distinguished contributions to the profession of rock mechanics and rock engineering. Dr. Barton is the sixth recipient of the Award that is made every four years. Dr. Barton was selected during the ISRM Council Meeting in New Delhi in October 2010 and will receive the award and deliver the Müller lecture at the 12<sup>th</sup> ISRM Congress to be held in Beijing in October 2011.*

**Vrkljan:** Even before you turned 30, you developed the Q system that is now used all over the world for the description of rock masses and for the design of support systems for tunnels and large caverns. Even earlier, you defined in your doctoral thesis the empirical criterion for the strength of discontinuities.

**How is it possible that you have conceived, already in your student days, the ideas that have resulted in methods that are nowadays widely accepted in the international professional community? What message could you pass on to our young colleagues, how to make a good start?**

**Barton:** For sure I have had some fortunate opportunities and fateful parental guidance in teenage and later years, which eventually focussed around my much admired and quiet-spoken civil engineering and soil mechanics professor Kevin Nash at King's College, the late ISSMFE general secretary in Dr. Bjerrum's time as President. Prof. Nash persuaded me to apply to King's College (after I had failed to enter Oxford University with no Latin O-level, and modest silence about being a fast runner). He also dissuaded me later from leaving mid-degree for a distance-running training-camp year in Australia, and he introduced me to Laurits Bjerrum who was visiting London ("why don't you come to NGI"?). Most crucially Nash interested me in a new rock slope stability project at Imperial College, where Peter Cundall of later UDEC/3DEC/FLAC/PFC fame, and John Sharp and David Pentz became my best friends during our Ph.D studies, each one full of enthusiasm about our common rock slope projects. So I joined a creative group and contributions inevitably followed, all related with the importance of rock joints. So by a hair's breadth I did not go into soil mechanics, thanks actually to my soil mechanics professor (Was he clairvoyant?).

A year later Evert Hoek joined our IC/RSM group next to Hyde Park, and became a valued advisor and professor and research-funds acquirer through RTZ. My subsequent ideal surroundings were in Norway (rock-and-joints are everywhere), where we went as a young family 'for one year' (this has stretched to 40 years). Research funds from the Norwegian State Power Board (Statkraft) and hydropower projects and challenging questions were in good supply ("how much air will leak out of in-mountain unlined 7 MPa compressed air surge chambers" was my first challenge, followed by "why are there such differences in the deformations recorded in Norwegian hydropower caverns"?). The latter took >6 months to answer – the 'Q-system' development was needed first. I was surrounded by excellent colleagues at NGI, and was taken on field visits with older colleagues like Reidar Lien, 'doubling the cost' that later payed off with our 1974 publication and its results.

How to make a good start as a young engineer or scientist? Seek an active university group and one that has a reputation for doing research in a country with challenging projects. Be sufficiently obstinate to follow your beliefs, and question the status-quo...easier 40 years ago...but there are many improvements needed in rock mechanics also today. Some have even occurred in 2011.

**Vrkljan:** In 1960s, leaders of the International Conference on Soil Mechanics considered that the rock mechanics should be developed in the scope of the soil mechanics, as one of its disciplines. This point of view was clearly expressed by Bjerum who was speaking on behalf of Casagrande (President of the International Conference on Soil Mechanics) at the annual congress of the Austrian Society for Rock Mechanics in Salzburg in 1962. It is known that the effect was quite the opposite and the International Society for Rock Mechanics was founded at that time. I am not quite sure that things have much changed in the meantime. This has been reflected in the change of name from International Society for Soil Mechanics and Foundation Engineering (ISSMFE) into the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) in 1997, and in the initiative launched by the present-day president of ISSMGE Prof. Jean-Louis BRIAUD to change the society's name once again to International Society for Geotechnical Engineering (ISGE). The establishment of FedIGS (Federation of the International Geo-engineering Societies) has been an attempt to reduce these differences but it remains to be seen if that attempt will prove successful.

**How do you look at the relationship between these two disciplines (it is implied here that the soil mechanics and rock mechanics also include geotechnical engineering in soil and rock) and the most difficult geotechnical problems actually lie in the boundary area in which these two disciplines overlap, i.e. in the zone between soft rocks and hard soils?**

**Barton:** I know that the journal 'Geotechnique' is mostly soil related, but the discipline name 'Geotechnical Engineering' actually covers a lot of the work performed in rock engineering, and as I presume we would not be suitable as members of 'ISGE', then it is not correct for them to 'take over' this discipline name. 'Geo' implies a geological origin, and the time scale for soil and sand deposits would be somewhere in 'the last fraction of a second before midnight' in relation to the multi-billion-years time scale of the much more variable medium tackled by rock engineers. So keep 'geo' for the larger time scale, and for everybody else.

As for 'the most difficult geotechnical problems', I would suggest that it is not only construction in saprolite that is difficult. In rock mechanics we have been misled into assuming we can add ' $c$ ' and  $\sigma' \tan \phi$ , following the soil mechanics lead for so long. In fact it should be ' $c$ ' then  $\sigma' \tan \phi$ . Mohr-Coulomb and Hoek-Brown do not describe the shear strength of rock masses anywhere close.

**Vrkljan:** Engineering geology, which is one of foundations of geotechnical engineering, is not always on good terms with soil mechanics and rock mechanics. It is known that Karl Terzaghi, as the father of soil mechanics, and Leopold Müller, as the father of rock mechanics, both considered themselves as professional engineering geologists. Terzaghi has left us with an incomplete book on engineering geology. Nevertheless, even their extremely positive attitude towards the engineering geology could not quench or appease the possible ambiguity and reservation that has been apparent between the three disciplines for a long period of time.

**In your opinion, what is the current role of engineering geology in geotechnical engineering? How should it be developed in the future in order to assist, to a greater extent, in the resolution of increasingly complex geotechnical problems?**

**Barton:** I think the role of engineering geology is very important, both in soil and rock engineering. There is incidentally an excellent 'new' book (now in English) with the title 'Geological Engineering' by Spanish authors from universities in Madrid, principally authors Dr. Vallejo and Dr. Ferrer. It is comprehensive, very well illustrated, and I would judge it to become a milestone publication for engineering geology, with a lot of useful soil and rock mechanics too. Engineering geology is part rock engineering, part soil engineering, part geology, part hydro-geology: indeed a challenging and very broad discipline.

**Vrkljan:** In your comprehensive monograph from 2006 "Rock Quality, Seismic Velocity, Attenuation and Anisotropy", you have dedicated a lot of space to geophysical methods. Much is currently expected from geophysical methods as they are fairly inexpensive when compared to traditional testing and investigation methods. They have been proven efficient during rock testing in laboratory and for deep testing during investigation of oil and gas deposits. In this area, Croatian seismologist Andrija Mohorovičić discovered the boundary between the Earth's crust and mantle while analyzing the sudden increase in the velocity of waves

caused by earthquake, and this phenomenon has been named after him (Moho and Morović discontinuity). However, in the sphere of engineering projects, geophysical methods have not as yet fulfilled expectations of geologists and geotechnical engineers.

**How do you think these methods will be developing in the future, and what are the chances that geophysics will achieve in geology and geotechnical engineering the results it is currently achieving in medicine?**

**Barton:** I believe that your partly negative opinion about geophysical methods 'not as yet fulfilling expectations' might be related with the geophysical difficulties in karstic regions, which I believe is an area you have particular experience of in Croatia. I believe that 'across the board' geophysics has been a great help in hydropower projects (dam foundations, tunnels etc.) around the world, already for 40-50 years (considering refraction seismic and simple cross-hole measurements). The use of cross-hole seismic tomography for the last 25 years has added an additional element of realism. The abilities to link velocity to rock mass quality (and attenuation to deformation modulus) are important in many projects. Some tunnel seismic methods also seem to be of help.

**Vrkljan:** In his keynote lecture given in 1982 at the 23<sup>rd</sup> US Symposium on Rock Mechanics, Croatian scientist professor Branko Ladanyi emphasized that one of the main problems in rock mechanics lies in the impossibility to directly measure basic rock mass properties because of the scale factor limitations (scale effects), and time and financing constraints. Although various field and laboratory test methods have been developed in the meantime, these limitations are still present.

**What is in your opinion about the role of field and laboratory testing in the definition of mechanical properties of rock mass? Especially in the light of the fact that, regardless of the increase in the scope of testing, it will always be too restricted when compared to the volume of rock mass influenced by geotechnical structures.**

**Barton:** Since borehole testing and in situ larger-scale testing in exploratory adits will always, as you say, be restricted in relation to the actual volume of the rock mass influenced by large structures like concrete arch dams, then the interpolating ability of seismic measurements to 'span' between testing locations and testing results (from boreholes, adits, plate-load tests etc) advertises itself as a possible means of 'averaging' and larger-scale measurement.

**Vrkljan:** Your Q system and Bieniawski's RMR system have been developed primarily for the tunnelling work and other underground construction. Modifications of these classifications, to enable assessment of slope stability, have also been published (SRM-Romana;  $Q_{SLOPE}$ ).

**What are the chances that classification systems for estimating slope stability will become as efficient as are the classifications used in tunnelling? Or maybe an another approach should be developed?**

**Barton:** Classification systems, such as the slightly modified Q-method called  $Q_{slope}$ , can be useful for estimating the safe slope angles of unreinforced rock slopes. Substitution of a limit equilibrium or other stability calculation by a classification method, in order to estimate slope-support requirements, seems less likely to be acceptable than it is in the case of tunnels.

**Vrkljan:** If we disregard earlier classifications (Terzaghi, Lauffer, Deere et al, Pacher et al), the following classifications have mostly been used since 1973: Q (Barton), RMR (Bieniawski), and the GSI system (Hoek). The Rmi classifications (Palmstrom) is also worth mentioning. Classifications are often used (especially GSI system for those planning to perform standard numerical modelling) for the site rock mass characterization (rock mass properties determination). After the GeoEng2000 workshop held in Melbourne in 2000, you have had a brief polemic with the discussion leaders (A. Palmstrom, D. Milne and W. Peck) about the role of water and stress in rock mass characterization.

**Now, ten years later, do you have anything to add about this issue?**

**Barton:** My concern remains to actively include stress and water rather than 'externalise' them when classifying/characterizing. Of more concern to me these days is the absurdity of the algebraic equations linked to GSI (which is only RMR (minus 5?) anyway. I do not believe, nor ever will believe, that one can look at a picture and 'classify' a rock mass. The childrens-method of diagram recognition is entirely inappropriate to the challenges of describing the anisotropic water-bearing medium that we call rock masses. It is time to question this wide-spread method, and the absurdly complex algebra 'links' to parameters, that are not actually empirically based.

**Vrkljan:** Over time you have linked the Q system with seismic velocities, rock mass deformability moduli and input parameters for numerical modelling of dam construction sites. You have developed Q<sub>TBM</sub> for the use of classification during machine-based excavation of tunnels, and the Q<sub>SLOPE</sub> for the slope stability estimation.

**Highly aware of your incredible creativity, we may expect that something new will come out of the "Q-workshop". Can you reveal at this time what that novelty might be?**

**Barton:** Because of my concern about the complex algebra that people are isolating themselves behind when using the downloadable, cease-to-use-libraries GSI/'RocScience' methods, I have been concerned about suggesting an alternative, and also am concerned about a widespread need to cease adding ' $c$ ' and ' $\sigma' \tan \phi$ '. Conventional continuum modelling with ' $c$  plus  $\sigma' \tan \phi$ ' (linear or non-linear) does not give anything approaching a good enough match to observation of stress-induced failure, so all the 'colour' in consultants and students appendices showing 'plastic zones' are actually better omitted, until a general improvement of method is adopted (degrade cohesion and mobilize friction at different strains). An alternative Q-based method, with degradation of ' $c$ ' (=CC) and mobilization of  $\Phi$ (=FC) has been tested recently with links to measured deformation, that shows promise.

**Vrkljan:** Almost one half of Croatian territory is covered with Dinaric karst, a unique phenomenon on an international scale. Some Croatian terms have actually been adopted in international terminology (polje, dolina, uvala). Not many people know that K. Terzaghi started to get interested in engineering geology precisely in Croatia while he was studying karst in 1909/1910 for a hydropower plant construction. In 1913, Terzaghi published his theory on the formation of poljes which was rejected by geologists, only to become widely accepted just a few years later. It seems that Terzaghi, who was at that time no more than 26 years old, looked too young to change their theories. Numerous road, hydropower and railway tunnels have been built in Croatian karst.

**Considering the unpredictability of karst, could you give us some additional explanations for the use of the classification in zones of intense dissolution of carbonate rocks?**

**Barton:** I was hoping not to get such a question as it is fundamentally difficult to characterise a void or numerous voids, except to give a size distribution and a mass-porosity distribution. Since the voids themselves have no valid values of  $J_n$ ,  $J_r$ ,  $J_a$  or SRF, but obviously have effectively zero RQD and 'infinitely' low  $J_w$  (or 'infinitely' high permeability), any use of standard classification methods like Q or RMR are inevitably suspect. Can one concentrate on the strength (or weakness) of the limestone lattice-work that presently remains 'intact', in combination with the void distributions? That presumably could be classified, and the resulting moduli converted into a fraction corresponding to the void ratio distribution? Definitely problematic.

While observing small slopes in limestones in Greece recently, it became obvious why limestones do not readily produce 'saprolitic' (in situ weathered fabric). It seems that the joints, instead of getting clogged with weathering products allowing slow weathering of the matrix, in practice become so permeable and gapped ( $10^3$  to  $10^6$  increase in permeability?) that 'very soon' the matrix blocks become detached and roll downhill, so a saprolitic condition is impossible if there are gradients of water flow or terrain involved. Obvious to those living in Croatia for sure.

**Vrkljan:** At the Rabcewicz-Geomechanical Colloquium held in Salzburg in 1993, on the occasion on the thirtieth anniversary of the birth of the New Austrian Tunnelling Method, professor K. Kovari criticized the NATM concept. According to Prof. Gudehus, the polemic that was started between Prof. Kovari and Austrian experts was exceeded only by the well know polemic between Terzaghi and Fillunger, which ended quite tragically. It seems that the remaining scientific and professional community observed this event without too much interest.

**As the principles of tunnelling, known as NATM, are generally accepted in tunnelling, and not expecting you to back any of the sides in this polemic, it would be quite interesting to hear your opinion about the matter.**

**Barton:** I do not recall the specific arguments of Kovari, or why he upset the Austrians so much – except that he was an invited keynote lecturer. (I was present in Salzburg the following year with an 'NMT' lecture, and registered the Austrian's continued frustration with his opinions and strong critique.... "not a scientific method" etc). I have personally recommended combining the best aspects of NATM and those of NMT, and wondered in publications why S(fr) has taken so long to be accepted in Austria in relation to the long-preferred S(mr). In Norway we ceased to use S(mr) nearly 30 years ago. Recently I recommended 4 km of NATM and 8 km of NMT at twelve large (19m) tunnels with difficult portal areas and long zones of saprolite. The NMT was where Q was from 5 to 25 in excellent granites in general. Remember that our 62 m span Gjovik Cavern has 10 cm S(fr) and bolting as permanent support, with Q from 2 to 30, RQD from 60 to 90, and UCS below 100 MPa.

One other aspect that could be improved in NATM, besides more generally adopting single-process S(fr), would be the use of *boltable* lattice girders. The RRS ribs of reinforced shotcrete used in NMT, e.g. when  $Q < 0.1$ , are systematically bolted and far superior to lattice girders or steel sets, which rely on rock deformation and footing foundation resistance before they start to feebly resist radial loads. Never use the Q-system for design with lattice girders or steel arches – it will not work, as the lattice girders are too poor in resisting loading.

**Vrkljan:** We are presently witnessing a veritable explosion of computer-based technologies. What used to be accessible, just a few decades ago, to the largest research centres only, can now be found in the bag of every engineer.

**To what extent will this exponential development of information science influence development of rock mechanics, especially as we know that we are still not able to precisely define input parameters in the models we already have or in models that are now being developed?**

**Barton:** The 'bag of every engineer' unfortunately may not contain very reliable tools, as the input data connection to parameters may be concealed behind algebra, and the rock mass does not generally behave as a continuum. The exponential development of information is good, but the quality of the most used information may be of mixed quality. It is dangerous to 'download' from one source, as the bias of the provider prevents advances being made in understanding, as when undertaking visits to libraries and performing original thinking, instead of using someone else's thinking.

**Vrkljan:** Demands placed on rock mechanics are becoming more and more complex. Underground mines are getting increasingly deeper, the size of surface excavations is also increasing, transport tunnels are becoming longer, the quantity of nuclear waste is increasing, and earthquakes are the constant threat to sensitive structures. Cities are gaining a third dimension by penetrating into the underground space.

**How do you see further development of rock mechanics and rock engineering? What are the priorities in the near future?**

**Barton:** In a recent workshop provided by a lecturer from one of the largest service companies working in the petroleum industry, it was stated that geomechanics is very important but that it has "not really developed in 100 years". In fact there are important developments that multi-discipline oil company teams seem to be missing, judging by their use of incorrect methods too, and right this year there is a new strength criterion for rock that outperforms Mohr-Coulomb and Hoek-Brown, following a more correct curvature, so less triaxial tests are required.

There are also important moves in some quarters (Canada, USA, Sweden, Norway, India, among others) to start to model the shear failure of rock masses in a more realistic way, by not adding cohesion and friction, but degrading and mobilizing separately. Here there is much work to be done, as dilation, modelled for years in rock joint behaviour, needs also to be a stress-dependent and strain-dependent part of rock mass modelling. There is also the need to understand that deformation modulus (and seismic velocity) may increase with depth due to stress effects alone, not just due to rock quality improvements. There is a long way to go in our complex subject, so plenty of future Ph.D. topics. Joint behaviour remains, after 50 years or more, as a key to better understanding. Isotropic continuum modelling will continue to teach us very little, as the rock mass will continue to not cooperate.

**Vrkljan:** At the end of this conversation, I wish to congratulate you on all your achievements and especially on the 6<sup>th</sup> Müller award which is bestowed every four years by the International Society for Rock Mechanics in the honour and memory of Prof. Leopold Müller, the founder of ISRM. Thank you very much for having participated in the EUROCK 2009 ISRM symposium in Dubrovnik, through which you have provided a great impetus and support to our geotechnical community. Thank you also for your readiness to hold this short course. Finally, I wish you a lot of success in personal life and in all your professional endeavours.

**Barton:** Thank you Ivan for your positive attitude to my developments, and for a range of unexpected and challenging questions! It was (of course) a great pleasure to be invited to Zagreb.