An interview with Dr. Nick Barton

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SY: What was the motivation for you for choosing civil engineering?

NB: For some reason unknown, when I was away at boarding school in Oxford as a 15-16 year-old I started to measure temperatures in the air and in the river (where we were allowed to swim, when the water was warm enough). I had a floating thermometer in the water and one in a tree that was easy to climb. I graphed temperatures every day for a year or two. I also made a (temporary) giant pendulum from a fourth-floor study room, 15m above the ground, shared with five or six fellow-students – until forbidden by the boarding-house master. The weight at the other end, swinging close to a lot of (too many!) windows on the first floor, was about 100 kg of recently acquired weight-training equipment I had bought second-hand – for supplementing my distance running training. (Later the school gym purchased a whole set of weights for everyone to use, when they saw my running results improving?) The pendulum period (time for one cycle) - makes a good exam question (?) – was I am guessing, about 12-13 seconds? I also made a small electric motor from scratch, following a physics lesson – winding the coils myself and mounting the rotating parts, the split-copper cylinder and copper brushes inside a big magnet – and had an acid-accumulator and wires from under the floor of the student study – for which I got into a lot of trouble, after discovery. In the vacations back in Wales I used to make 'earth dams' and artificial floods down a 30cm wide stream that flowed into the land close to our 300 years-old stone cottage in the Welsh hills. The dam was 1 m high, made of turf (cut pieces of 'earth-and-grass', compacted, and had a bottom outlet – a 30 cm pipe with a circular sealing plate that I had to open 'by hand' – pushing hard on a wooden pole from downstream – through the 2m wide dam – and stand back quickly. Even 1m head or water made an impressive full-bore 2-3 m 'jet' – and the pool/'reservoir' was big enough (10 m^3?) to make 'serious miniature flooding' down-stream. I also once helped friends of the family clear stones from a small reservoir (filled by a flood). This reservoir was for a private small-hydro, made for a big country estate 50 years earlier. It was used to drive a private saw mill for

‘harvesting’ trees on the estate, heat ‘green-houses’ for growing plants – and for light and heating of the 100 rooms estate! So many small things added up: an interest in physics and water, and temperature, and pressure, and hydropower – and floods!

(By chance – years later, when I was 18 years-old, my future soil mechanics professor was holidaying at this same ‘private-hydropower’ house, when our friends were less rich and had to rent-out holiday flats. ‘Why don’t you apply to King’s College – but read my book about civil engineering first’ he said, when we met for the first time! So I did both – and four years later became ‘a civil engineer’. The same professor (Kevin Nash) also introduced me to the rock slope research project at Imperial College – where I joined electrical engineer (!) Peter Cundall (by chance). A year later Evert Hoek joined and led our group, by now half a dozen researchers, and soon to expand more. A year or two later Prof. Nash introduced me to Laurits Bjerrum the director of NGI in Oslo. We three had lunch in London – I was then the poor doctoral student. Both Kevin Nash and Laurits Bjerrum were very charming and also very persuasive people – at that time they were respectively the president and gen. sec. of ISSMFE – the international soil mechanics society. ‘When you are finished at Imperial College why don’t you apply to NGI – we have a lot of rock in Norway’! So I did that too, and now have been 45 years in Norway, 25 of them at NGI pre-2000.

SY: How would you define yourself, a civil engineer, an engineering geologist, a rock engineer, or something else?

NB: The answer has to be something of each. The civil engineering was formally the result of three years of university study for a B.Sc. – in London, while the rock mechanics was the result of the next four years of research into shear strength of rock fractures and rock slope stability, which led to a Ph.D. at Imperial College – called in the far east ‘Empirical College’ (a mistake – but appropriate) when I am introduced to give a lecture – on empirical things like the Q-system, JRC, JCS, Q_{TBM} etc. At Imperial College my practical back-ground resulted in me making a ‘model-material fracture-generating guillotine’ – with two long opposed blades. So I could make 40,000 interlocking blocks for (almost) 4 x 2m physical models of steep slopes – and see how they failed under different horizontal (and of course vertical, gravity induced) stress. Later I used this technique for large-cavern studies at NGI – we were investigating the possibility of 50m span caverns for (underground) nuclear power reactor vessels – this was in 1976, 77 just before UDEC made it possible to do numerical modelling instead of physical modelling. (See Barton and Hansteen, 1978 in my web-site www.nickbarton.com). The ‘engineering geologist’ part of the question continues to this day – learning something new from almost each project, now in a total of 38 countries. It has been a privilege to travel to so many places – often in beautiful mountains at hydro-power projects. Geology continues to come by ‘osmosis’, by seeing and learning, not by formal training.

SY: What is the main necessity for a rock mass classification?

NB: We can test a steel wire for tensile strength, and crush a cube of concrete for its compression strength. We can more or less test a representative laboratory sample of soil or sand, especially if layering can be preserved. So can we also test representive samples of rock? Yes – at small scale – for uniaxial compression strength, for instance, but 500-1000m^3 of rock that we need to describe, surrounding the last 5 to 10m of a tunnel – this is too big to test – except remotely like with seismic velocity or permeability – each of them giving just partial information. That is why we need to assess the combined effect of the rock, the joints, the minor

faults (or a whole tunnel-section/mining section if we have reached a major fault). In mining, the stopes may be so huge – depends on rock quality – that (quantified) description, meaning classification or characterization by numbers – such as Q' = RQD/Jn x Jr/Ja – is very useful because we are way-beyond testing scale: back analysis – yes, and therefore useful case records can be obtained for the future. I was lucky to have a lot of these case records accessible from tunnelling literature.

SY: What was the motivation of developing the Q system?

NB: There was no classification method that we knew about in 1973. (Bieniawski, 1973 was published in a South African journal, and was not yet known to us in Norway). We just had RQD from Deere from about 1967. So when I was given the question from our Norwegian State Power Board via my section head at NGI in 1973: 'What is the reason for the big range of deformations measured in our underground power houses'? there was not very much more than rock descriptions like: 'quite massive rock', 'very jointed', 'very high stress' etc. And depth differences and support differences all had to be considered. So without planning, and without a fixed budget, the accidental start of 'Q' began – and finished 6 months later, after successive re-analysis of 212 case records on tunnels and caverns, but very few mining cases, as there was less detailed description of the rock masses. I started with RQD and number of joints sets – a suggestion from Cecil, 1960. He was a Ph.D. student of Deere who was sent to Norway and Sweden to collect tunnel and cavern case records. His 90 cases were a great start for me. Each had a sketch of jointing and ½ page of description. So I tested a new 'Jn' (number of joint sets) together with his RQD estimates, then included roughness 'Jr' and later clay-infilling 'Ja', then stress/strength 'SRF' and finally water 'Jw'. And I collected about 120 more case records form the literature. The ratings of each of the six parameters were derived by repetitive trial-and-error, to best fit each tunnel or cavern case record. Later I found that Jr/Ja was like friction coefficient, and when many years later I included UCS directly (Qc = Q x UCS/100 – with UCS in MPa) I found that Qc was like 'c' x tan 'φ' (not + like in the Coulomb equation). Why 'x' I do not have an explanation yet, although we do know than c and phi cannot be added. The case records – concerning needed amounts of shotcrete and bolting – were effectively reflecting the sufficient or insufficient values of c and φ in the different rock masses i.e. less, or more shotcrete and bolting had been needed to make the tunnels and caverns stable. So it was almost like a back-analysis of 'near-failure' (or of 'near-stability') but obviously leaning towards conservatism, as no failure and only stability were wanted – but at minimal cost. So I was effectively collecting 'accurate' thicknesses of shotcrete and 'accurate' numbers of bolts. And no science-killing concrete – when this was not needed.

SY: Can you state the superiorities over other rock mass classification systems?

NB: I think there are two or three reasons – that occurred by chance, not by design. One is that the number of joint sets is so important. This is a major weakness of RMR (and therefore GSI if linking these two by GSI ≈RMR -5.) Also, an equation based on a/b x c/d x e/f more or less may make a scale similar to a $\log_{10}$ scale (with the help of some of the larger ratings like Jn = 20 for soil-like conditions). The nature of 'geology' – the range from massive intact hard rock to a wet, weak, clay-bearing fault zone, obviously varies over orders of magnitude of strength or stiffness, so 1000 to 0.001 (as in the Q-range) is automatically much more realistic than 10 to 100 – more or less the range of RMR because of the (only) adding of ratings. A one

order of magnitude range (5 to 100 to take the maximum) is grossly inadequate for describing almost any natural variation. The parameter pairs RQD/Jn and Jr/Ja – not by design but by the result of case record analysis, represent more or less relative block size and inter-block frictional strength. In retrospect this is a very powerful representation of the degree of stability or instability, and is also aided by SRF and Jw when these are needed. The formation of Q also makes it easy to argue in a logical way for how the parameters (almost all of them) can be improved by pre-grouting, as we do ahead of a tunnel. All the above advantages seem to be absent in RMR and GSI.

SY: Is there any statistics of usage of Q system as a rock mass classification system over other systems?

NB: I am not aware if there this. But there are some country-by-country favourite methods for sure. Some prefer RMR, and a lot of optimistic numerical modellers prefer GSI (because they then believe they can use Hoek-Brown), and plenty of others use Q, especially because of the use of Q' (the first four parameters) in mining stope dimensioning (eventually with cable anchors). Concerning GSI/RMR, remember that rock masses do not fail due to '$c + \sigma_n \tan \varphi$'. These parameters are not mobilized simultaneously. The GSI-HB link to unknown shear strength curves is true 'black-box' – look at the equations for 'c' and 'φ' and try to evaluate where you would see the effect of undiscovered clay-filled joints, or an extra joint set. It is virtually impossible? In Q it is so easy to see these intended effects: reduced Jr/Ja, increased Jn, increased support.

SY: What is your future remarks for rock engineering realm?

NB: Look out for some new things about 'stress-induced' failure around deep tunnels or deep mining excavations. We think the ratio of maximum induced stress divided by UCS is important. In fact it is the ratio of tensile strength and Poisson's ratio (σ_t/ν) that determines the initiation of tensile (actually extensional) fracturing, and the initiation of acoustic emission. The common ratio we all have used – also in the Q-system for SRF, has been σ_{max}/UCS $\geq$0.4. We have learned from experience that means fracturing, and at much higher stress: rock bursting. The latter is the unstable propagation in shear. The extensional tensile failure can actually occur when all stresses are compressive – which they are a few cm into the wall of any tunnel or mine roadway. The 'magic' 0.4 stress/strength ratio is explained by the common values of tensile strength and Poisson's ratio (σ_t/ν). See Barton and Shen, 2016 very soon, and Shen and Barton, 2017 later this year.

SY: Finally, what was your impression about your Trabzon journey and International Black Sea Mining & Tunnelling Symposium?

NB: It was a great pleasure to be invited and to take part with a course, and especially to be invited to dinner each day with a very warm friendly group of colleagues. Of course you are all Turkish so what different should I have expected. Anyway – thank you sincerely! It was a very good experience.

SY: Iwould like to present my sincere thanks to Nick for sharing his valuable thoughts with us.