

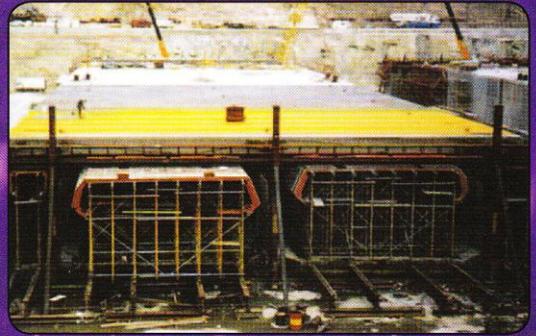
WORLD TUNNELLING

September 2011

Canada

Drill & blast: Norway

Sprayed waterproofing



stirling lloyd

THE TECHNOLOGY OF PROTECTION

www.stirlinglloyd.com

www.world-tunnelling.com

More debate needed

“YOU should have had that paper peer-reviewed before you published it,” one of my colleagues admonished me recently. He was referring to the article published in *WT* last month by Dr Walter Wittke and Dr René Sommer (WBI Consulting Engineers) on rock-classification systems.

In the paper, the authors take a very critical look at rock mechanical models and classification systems, arguing that their “striking deficiencies can lead to unsafe design or over-design”. I make no apologies for including that paper in *WT* last month. It had been offered to me directly by Dr Martin Wittke of WBI Consulting, a well-respected engineering consultancy.

The paper had been compiled recently, written well and was quite forthright in its view, and that sort of thing is perfect for this magazine: new ideas, re-examining orthodox approaches, overturning established theories, and all providing a stimulating learning experience.

I saw no reason to peer-review the paper. After all, this is a business title; is not an academic journal and it is not tied to any institution that might seek to influence editorial policy.

But, it was only fair to warn Dr Barton, a champion of the Q-system, of the impending publication. I contacted him as soon as the article appeared on the *WT* website (www.world-tunnelling.com) in case he might not be too pleased at the implications of the article. I was right. He wasn't.

“You should have had that paper peer-reviewed before you published it,” he told me. So, Dr Barton was given the right of reply in defence of his theories,

WEB ADDRESS www.world-tunnelling.com

given that the Q-System was so obviously under scrutiny. He promised a swift, robust response, and within a couple of days that is exactly what I got – a spirited, lengthy defence, which is published in full in this issue (pp13-17).

How good all this is. Two leading lights of the industry discussing what has proved to be a key element in tunnel-support design over the past 40-odd years. And what's wrong with that?

It is only by constantly reviewing, examining and, if necessary, modifying our long-held beliefs that we progress. In fact, that is how progress has been achieved throughout history, not only in tunnelling but in all fields of human endeavour.

That is not to say that established rock-classification systems are inadequate and need to be modified: I am not an engineer and my knowledge of engineering mechanics is too feeble to allow me to reach that sort of conclusion.

But I do know that discussion is a great way to learn, stimulate, and understand others and where they are coming from, even if sometimes it is our egos that are doing the talking and driving our actions.

So, if last month's article by Dr Wittke was a bit of an eye-opener, this month's by Dr Barton is equally insightful; both men, I believe, have benefitted readers of this magazine and tunnelling generally, so let's have more of it.

George Demetri, Editor
george.demetri@aspermontuk.com



Regular

Global news 3

Features

Leaders 10

Letter to the Editor 13

Canada 19

Drill & blast 23

Project Russia 27

Waterproofing 30

Cover

A selection of images showing Stirling Lloyd sprayed waterproofing systems used on tunnelling projects worldwide. These include the Buenos Aires Metro in Argentina where some 20,000m² of Integritank HF membrane is being spray-applied to an excavated tunnel, used to house a new four-track wide parking garage for Metro trains.

www.stirlinglloyd.com



Editorial

Editor George Demetri T +44 (0)20 7216 6051 E george.demetri@aspermontuk.com

Production editor Tim Peters

Sub editors Vickie Johnstone / Woody Phillips

Editorial enquiries T +44 (0)20 7216 6060 F +44 (0)20 7216 6050 www.world-tunnelling.com

Advertising production Sharon Evans E sharon.evans@aspermontuk.com

Advertisement offices

Head office Contact: Gareth Hector,
Advertisement and new media director

Aspermont UK, Albert House, 1 Singer Street, London EC2A 4BQ, UK
T +44 (0)20 7216 6060 F +44 (0)20 7216 6050
E gareth.hector@aspermontuk.com

North America, Australia, UK & Rest of World

Contact: Neil Wightman, advertising sales manager
T +44 (0)20 7216 6053 E neil.wightman@aspermontuk.com

Germany & Austria Contact: Gunter Schneider

GSM International, Postfach 20 21 06,
D-41552 Kaat, Germany.
T +49 2131 511801 E info@gsm-international.eu

Italy & Switzerland Contacts: Fabio Potesta, Daniela Chiusa

Media Point and Communications SRL, Corte Lambruschini –
C.so Buenos Aires 8-V° piano Int. 7 16129 Genova, Italy.
T +39 010 5704948 F +39 010 5530088
E info@mediapointsrl.it / daniela.chiusa@mediapointsrl.it

Japan Contact: K Yamazaki

6-10-13 Nishiogu Arakawa-ku, Tokyo 116-0011 Japan
Kazumi Yamazaki/Accot Corp T +81 3 3800-3229
F +81 3 3800 3844 E accot@ga2.so-net.ne.jp

Scandinavia Contact: Richard Dolan

Aspermont UK, Albert House, 1 Singer Street, London EC2A 4BQ, UK
T +44 (0)20 7216 6086 F +44 (0)20 7216 6050
E richard.dolan@mining-journal.com

Subscriptions and circulation Stuart Balk T +44 (0)20 7216 6064 E stuart.balk@aspermontuk.com

Subscription enquiries T +44 (0)20 8955 7050 F +44 (0)20 8421 8244 E subscriptions@aspermontuk.com
PO Box 1045, Bournehall House, Bournehall Road, Bushey WD23 3ZQ, UK

Editorial director Chris Hinde

Chief executive officer David Nizol

Chairman Andrew Kent

Annual subscription –
UK and Europe €95.00 (160.00 euros)
Rest of the world US\$170.00. Additional current copies are available to subscribers at £12 (US\$21; €18) each

World Tunnelling (ISSN 1756-4107) USPS No: 023-551 is published monthly (except January & July) by Aspermont UK, Albert House, 1 Singer St, London EC2A 4BQ, UK. Printed by Stephens & George Magazines, Merthyr Tydfil, UK

The 2011 **US annual subscription** price is US\$170. Airfreight and mailing in the US by Agent named Air Business, c/o WorldNet Shipping USA Inc, 155-11 146th Avenue, Jamaica, New York, NY11434. Periodicals postage paid at Jamaica NY 11431

US Postmaster: send address changes to *World Tunnelling*, Air Business Ltd, c/o WorldNet Shipping USA Inc, 155-11 146th Avenue, Jamaica, New York, NY11434

Subscription records are maintained at Aspermont UK, PO Box 1045, Bournehall House, Bournehall Road, Bushey WD23 3ZQ

Aspermont UK, publisher and owner of *World Tunnelling* (‘the publisher’) and each of its directors, officers, employees, advisers and agents and related entities do not make any warranty whatsoever as to the accuracy or reliability of any information, estimates, opinions, conclusions or recommendations contained in this publication and, to the maximum extent permitted by law, the publisher disclaims all liability and responsibility for any direct or indirect loss or damage which may be suffered by any person or entity through relying on anything contained in, or omitted from, this publication whether as a result of negligence on the part of the publisher or not. Balance should not be placed on the contents of this magazine in making a commercial or other decision and all persons are advised to seek independent professional advice in this regard.

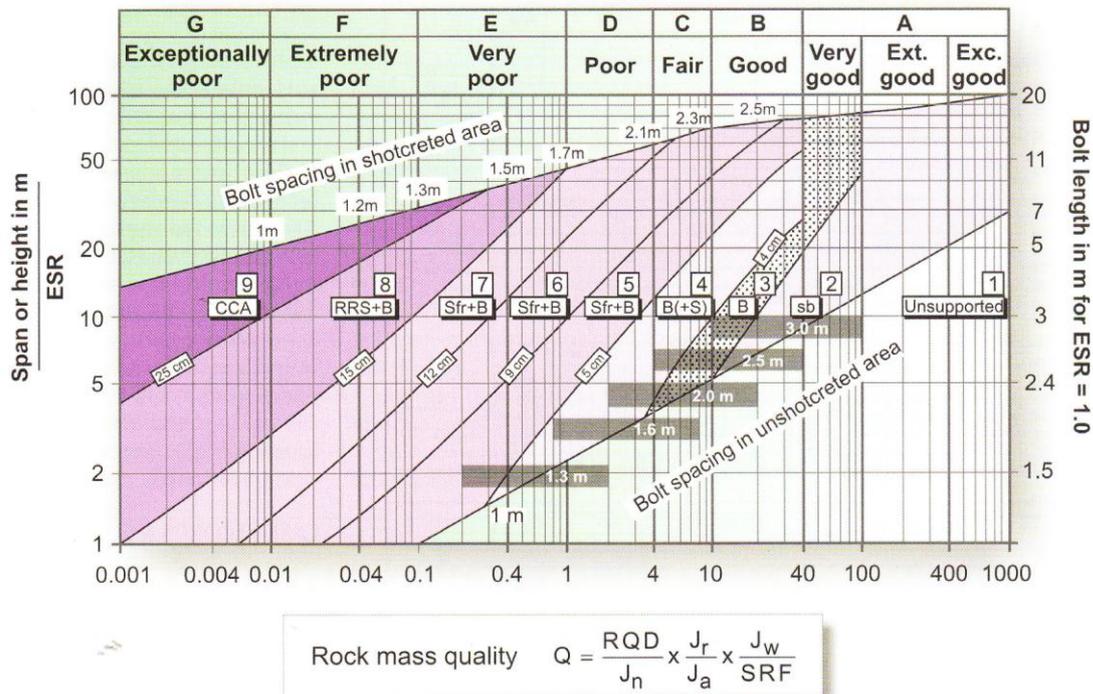
 **Aspermont UK**
Information for Industry

 **BPA**
WORLDWIDE

© Aspermont UK 2011 ISSN 1756-4107
A member of BPA Worldwide

A measured response

In a letter addressed to the editor, Nick Barton outlines the discrepancies and inaccuracies that he sees in the paper 'Designs in Jointed Rock', by Walter Wittke and René Sommer, published last month in *World Tunnelling*



It should be gratifying to have one's first paper on tunnelling referred to, and criticised, in the pages of *World Tunnelling* – 37 years after publication. However, the Wittke and Sommer (WBI company) comparison of their favoured FEM-based tunnel design method, with their limited understanding of rock mass classification, shows that the authors have made little attempt to follow developments in this field.

They reproduce the very first Q-based 'support selection' figure from 1974, with 38 support categories (needing tables for support selection), not mentioning that B + S(mr) – mesh reinforced shotcrete – was the recommended 'lining' at that time.

Since 1993, the Q-related support selection chart was specifically updated for B + S(fr) – fibre-reinforced shotcrete, which has been used

commercially in Norway since 1978. Perhaps the authors have another reason for not mentioning this difference if the cumbersome S(mr) is still in use on some of their German projects. It still seems to be in use in Austria, judging by NATM advertisements.

Surprisingly, Wittke and Sommer do not reproduce the widely referred B+S(fr) support selection chart, originating from Grimstad and Barton, 1993, and Barton and Grimstad, 1994 (the latter published in Austria in English).

However, they must have seen the more updated support chart (reproduced here in

colour (figure 1)) since, as one of their topics for Q-critique, they selected a figure about bolt spacing from this period.

Possibly, this figure has been reproduced from others who were also criticising Q. Such people have demonstrated a tendency to gather support from each other, some not even reading the paper being criticised, judging by the comments made.

In Scandinavia and many other countries, the less efficient and less safe-to-apply S(mr) tunnel 'lining' method ceased to be used decades ago. Tunnel workers have been injured in several countries during its three-process application.

The term 'shotcrete membrane', frequently used by the authors, is not used in English. They do not define, perhaps deliberately, what they mean by this; ie whether S(mr) or S(fr). There is an important difference because S(fr) can be

“Such people have demonstrated a tendency to gather support from each other, some not even reading the paper being criticised”

LETTER TO THE EDITOR

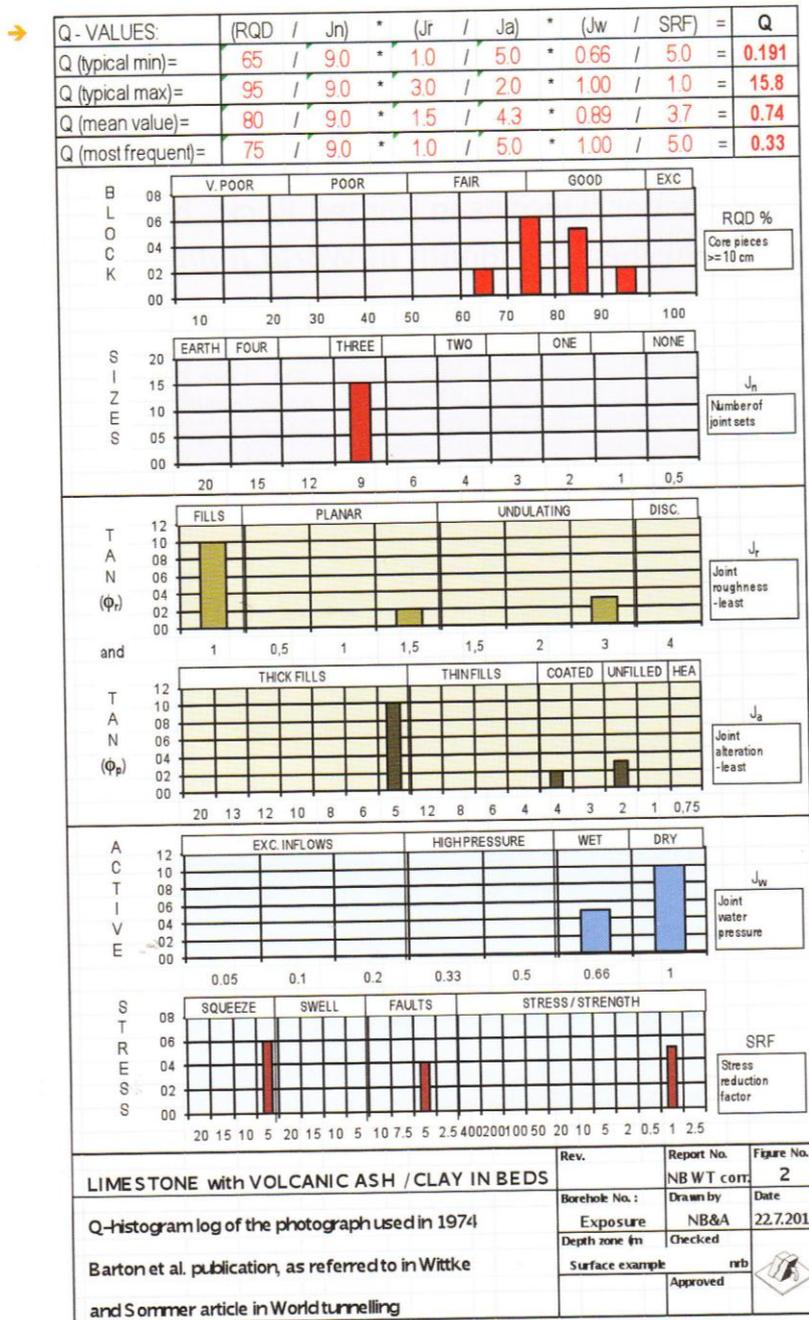


Figure 2: limestone with volcanic ash/clay in beds. Q-histogram log of the photograph used in the 1974 Barton et al publication, as referred to in the Wittke and Sommer article published in World Tunnelling, July/August 2011

Table 1

The remarkably out-of-date reference to the Q-system (1974) that the authors, Wittke and Sommer, seem to have just discovered, or use deliberately:

“A total of 38 support classes are defined, from which support class 1 requires almost no support, whereas for support class 38, the largest amount of support is necessary (figure 4). For each class, the amount of support can be taken from corresponding tables”

“The writer of this response has estimated that at least 2,000km of Norway’s 5,000km of tunnels have had ‘design assistance’ from Q-system application”

applied immediately (also above the muck pile) and is active much earlier, and it does not allow rockmass loosening to the same extent as S(mr), steel arches or lattice girders.

This difference in approaches is important because it is a delaying and therefore cost-driving difference, so that a typical ‘NATM-style’ tunnel (as in the case of their Österfeld tunnel example), may be from three to seven times more expensive than an NMT (Norwegian Method of Tunnelling) tunnel, based on prices/km seen in the last ten years in international tunnelling magazines. Of course, poorer rock may play a role in this cost difference in parts or all of many NATM-style tunnels, but not so frequently as one might expect, based on cost and time differences.

CASE RECORDS & SUPPORT SELECTION

Before addressing some shortcomings in the authors’ understanding of methods different from their own FEM-based design, a short description of the background of the Q-development will be given; this may explain why the authors favour one method (FEM), while others, with perhaps hundreds of kilometres of tunnels to advise on, have to base a lot of trust in classification.

As an illustration, one can mention the approximately 3,500km of hydropower-related tunnels in Norway, and some 1,500km of road and rail tunnels. There was a slight dominance of Scandinavian hydropower-related tunnel and cavern case records in the 1974 Q-development (212 cases), while the 1987-93 update (to Sfr) with Grimstad’s 1,050 cases was mostly based on road tunnels that had not been designed by classification with Q.

From figure 1, one can see readily the impossibility of one of the author’s (by misusing a 37-year-old paper) Q-based support solutions for their Österfeld Tunnel study, where they presume (somehow) that rockbolts at 1m centres (B 1m c/c) are combined with 30mm of ‘shotcrete membrane’ in a Q-based design. The authors need to withdraw and correct their error: it is an incorrect basis for critique and they have therefore wasted their time analysing such a case using FEM analysis.

Since 1987, the writer has always collected data using Q-histograms to represent the

LETTER TO THE EDITOR

typically variable rock mass properties (figure 2). A locally-applicable single Q-value may finally be used for a given domain or length of tunnel, but the source of this Q-value (from at least six parameters) must never be forgotten.

Since the authors apparently believe that the Q-value is not affected by depth, they will have difficulty in accepting that eight parameters may be involved in selecting the components of Q. These include depth (= stress) and rock UCS.

Figure 2 demonstrates the use of Q-histogram logging of the 38-year-old photograph that was selected by Wittke and Sommer for part of their Q-critique. They also rotated the photo by 90° (figure 3), which is an important change that has not been accounted for in figure 2. Orientation changes may affect RQD, Jr/Ja and SRF, and especially the length of tunnel needing heavier (or lighter) support.

The writer of this response has estimated that at least 2,000km of Norway's 5,000km of tunnels have had 'design assistance' from Q-system application. The total may be much higher, as consultants outside the Norwegian Geotechnical Institute (NGI) have not ignored Q, though some have chosen to criticise it publicly.

The Norwegian Road and Rail authorities use Q, as have hydropower developers in the past

– also outside the considerable NGI application of Q-based methods. The Q-system is used for feasibility studies, interpreting core and seismic velocity, for tunnel and cavern-support design assistance, and eventually for follow-up with support-class selection. Also in Norway, deformation monitoring may be used in caverns and challenging tunnels.

At NGI, where the writer spent 25 years, there was a strong desire to make use of numerical models where appropriate, as well as using Q. At least 100 UDEC-BB BB (distinct element models, with Barton-Bandis joint modelling) and, obviously, a much smaller number of 3DEC-MC (Mohr-Coulomb) models, were performed in the period after 1985.

Usually, this was done to assist in cavern design rather than tunnels. This more comprehensive, time-consuming and therefore more costly method was also used for some prominent, but relatively short motorway tunnels in the Far East. Shotcrete and bolt loadings were checked, just as with FEM approaches.

Since neither we (nor other consultants) are able to collect input data and numerically model 'every 10m', when so much tunnelling is being performed worldwide, rock mass classification proves a valuable assistant in design and is used in many other countries

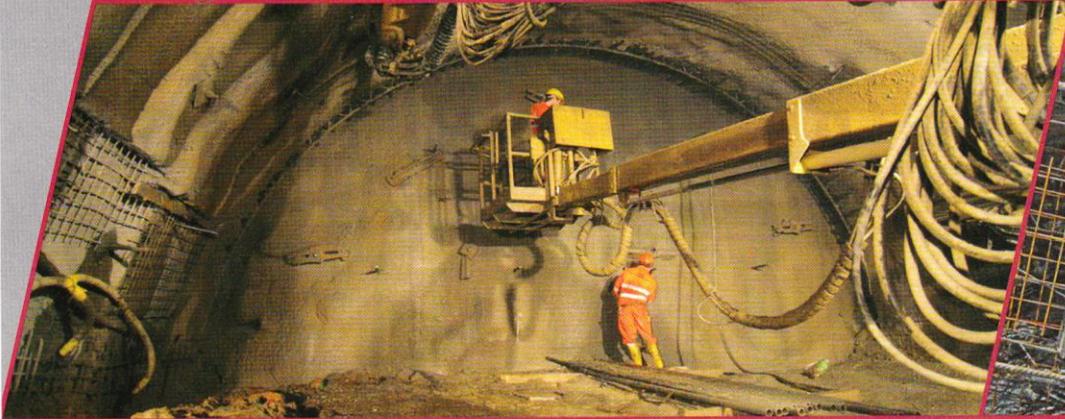
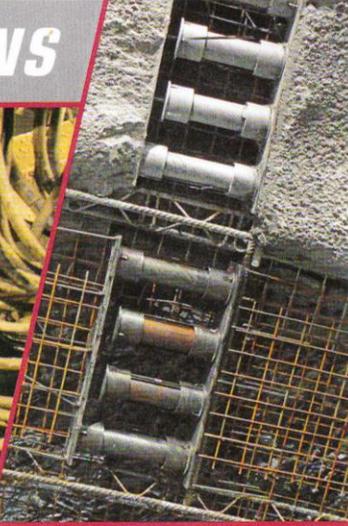
“The fact that the profession, outside WBI at least, has found RQD so useful is proved by its widespread international use almost 50 years after its introduction”

outside Norway. WBI may hopefully agree that not all metre lengths of all tunnels can have FEM-based design assistance.

MISUNDERSTOOD RQD & ROTATED OUTCROPS

Wittke and Sommer start their critique of Q (and indirectly RMR also) by giving a photographic example of a poorly recovered core, as compared to a borehole wall photo-scan. Because of the recovery process, or perhaps due to lack of rock strength, the core has fragmented into pieces much smaller than 100mm. If they had followed Deere's suggestions of long ago, they would need to reconsider whether such 'incompetent' rock (in the wall) deserved an RQD more than 0%. →

GROUND CONTROL SOLUTIONS

Each tunnel has a different geology and requires specific customized products and systems. DSI Tunneling Products and Systems match these requirements perfectly.

DSI is a leading provider in the development, production and application of ground control solutions to the tunneling market. In line with our strong service approach, we are always committed to satisfying our customers' demands.

DSI is global market leader in the development, production and application of Post-Tensioning and Geotechnical Systems as well as Concrete Accessories for the Construction industry. DSI is also the leading supplier of Ground Control Solutions for the Mining and Tunneling industry worldwide.

DYWIDAG-SYSTEMS INTERNATIONAL

North America USA South America Chile EMEA Austria APAC (ASEAN) Australia

www.dsi-tunneling.com



ALWAC SYSTEMS

- THREADBAR® Anchors
- Rebar Rock Bolts and Spiles
- IBO, IBI & DYWI® Drill
- Self-Drilling Bolts and Spiles
- OMEGA-BOLT®
- AT – Power Set Self-Drilling Bolts
- DYWIDAG Rock Bolts and Soil Nails
- Mortar-Mixing Pumps
- Steel Arches and TH-Beams
- Liner Plates
- Pantex® Lattice Girders
- LSC- (Lining Stress Controllers)
- AT – Pipe Umbrella Support System
- AT – Drainage System
- AT – GRP Injection System

LETTER TO THE EDITOR

“For some reason, Wittke and Sommer assume that the Q-value (and therefore recommended support) does not change with depth or orientation”

→ Another favourite method for ‘disqualifying’ RQD is to talk about 90mm and 110mm joint spacings. The fact that the profession, outside WBI at least, has found RQD so useful is proved by its continued and extremely widespread international use almost 50 years after its introduction by the distinguished University of Illinois Urbana Group, some of whom are still active as international consultants.

From the writer’s first-ever tunnelling publication, dating from 1974, the authors Wittke and Sommer selected a challenging photo example (figure 3). It consisted of bedded limestone with two perpendicular joint sets, and with most of the bedding planes filled with several centimetres of volcanic ash (now altered to clay).

The volcanic ash resulted from the high-volume volcanicity associated with the Oslo Graben. This is a north-south trending Permo-Carboniferous continental rift system, where a caldera collapse eventually occurred.

In figure 2, a hypothetical Q-histogram characterisation of this rock mass is shown (from a distant memory of a field visit 38 years ago, and from countless courses to thousands of short-course participants in many countries since then).

The photographic example is used as a contrast to other ‘regularly jointed’ ($J_n = 9$, three joint set) rock masses without clay. In the Q-histogram (figure 2), the character of all the joint sets can be presented. The SRF parameter



Figure 3: horizontally bedded rock and rotated 90° (right). $Q = 80/9 \times 1.0/5 \times 0.66/5 = 0.24$ (‘very poor’) was the classification example given for this rock mass (left only) in Barton et al, 1974

(last of six) has been given three possible categories, with a dominance of SRF = 5, as in 1974.

On the subject of joint or discontinuity orientation, the authors Wittke and Sommer perform the unusual exercise of rotating a rock mass by about 90° (roughly, as in figure 3), causing the adverse Jr/Ja clay-filled bedding planes to be near-vertical, instead of sub-horizontal. They then perform separate FEM analyses and demonstrate that an unchanged Q-value would not give the increased support needed with this adverse orientation.

The low estimated shear strength of the filled discontinuities is exceeded, even up to the surface, according to their analyses. This is an important demonstration, and confirms various designer’s experiences with low-strength, adversely-oriented structures. It is a dangerous orientation.

If this rock mass (left photo, figure 3) had been 100° rotated (giving vertical clay-filled bedding), then the presumption of a strong loading in the arch due to the low-friction fillings would suggest use of a ‘squeezing’ SRF factor (ie SRF > 5) whose magnitude would also depend on depth.

For some reason, Wittke and Sommer assume that the Q-value (and therefore recommended support) does not change with depth or orientation. They are doubly mistaken, but join others who think that orientation is neglected. It is not, if you know how to use the Q-system intelligently. This, of course, calls for subjectivity, which is hopefully also in evidence in their FEM modelling.

There are advantages in applying experience and intelligence when designing tunnels.

WIDELY VARYING BOLT SPACING

Concerning ‘classification system flaws’, Wittke and Sommer use some other Q-critic’s figure (Palmstrom?) derived from our 1993 paper, which applies to the big spread of bolt spacings in the case records concerning the rarer case of bolting without shotcrete. In our original publication, the present writer also commented on the “large spread in the data”, which reflected some over-design, with Q-values even far exceeding 20.

The writers of this 1993 paper used their combined experience to give a balanced recommendation, despite the wide spread of bolt spacings shown in case records. We do not share the Wittke and Sommer assumption that, as “no clear correlation between bolt spacing and Q” is seen, the Q-system must be ‘flawed’. Many different designers of these tunnels used a wide selection of bolt spacings and, perhaps, may have lacked systematic guidance. This is another possible interpretation and it seemed then, and still seems to be valid.

Figure 1 shows that since bolting without shotcrete is seldom used (Category 3 only), the Q-based method of selecting support is in fact rather conservative, and perhaps not so “unreliable” as Wittke and Sommer suggest. Where are the Q-based tunnel collapses? We know of some NATM and FEM-designed collapses outside Germany.

Robit®

ROCKTOOLS

Brilliant Solutions for Tunneling

See us at:

steinexpo 2011

Tel. +358 3 3140 3400 • robit@robit.fi • www.robit.fi

XXIX Convención Internacional de Minería 2011

IUT '11

14.-15. September 2011

LETTER TO THE EDITOR

“Of course, this thin shotcrete is entirely inadequate, and would/should never be approved by anyone with practical knowledge of either S(mr) or S(fr)”

INCORRECTLY SELECTED Q-SYSTEM SUPPORT

In a final example, Wittke and Sommer apply their FEM methods to an actual case: the shallow Österfeld Tunnel, situated in weak and deformable mudstones. A lining of 200-300mm of reinforced shotcrete: (S)mr, steel sets and rock bolts are used as temporary support during the three-stage excavation, and a final lining of concrete can be assumed.

Based on their estimates of bedding and joint friction angles of 20° and 30°, deformation moduli of 0.5 and 1.0GPa, and UCS of 9.5MPa, it is clear that this is an incompetent rockmass.

Without providing their estimations of the relevant Q-value, RMR or RMI value, Wittke and Sommer show three apparently widely different classification-based B+ ‘shotcrete membrane’ ‘WBI-solutions’, with (S)fr or (S)mr not defined as before.

They believe that shotcrete thicknesses should range from 30mm(!), through 50-100mm, to 200mm. They conclude that two of their supposed classification-based solutions would be overstressed (Q and RMR ‘designs’), while RMI would apparently not have an adequate safety margin for the ‘shotcrete membrane’.

Without addressing what they assumed was given by RMR and RMI in terms of bolt spacing and ‘shotcrete membrane’ thickness, it may be observed that in the case of ‘Q-system application’ they have selected systematic bolting: B 1m c/c (suggesting, with today’s Q-system application, a very low estimated value of $Q = 0.01$ (eg see figure 1).

This should mean, for an 11m-span road tunnel, that 250mm S(fr), RRS (rib-reinforced and bolted shotcrete arches) and probably a cast-concrete final lining would be recommended with the Q-system (it is on the boundary of CCA (cast-concrete arches)).

Exceptionally poor quality is implied by $Q = 0.01$. We, who apply NMT, also demand something like NATM in such cases, and the tunnel is correspondingly expensive in such locations. However, S(fr) and (bolted) RRS are safer and superior to S(mr) and (unbolted) lattice girders.

Unfortunately, Wittke and Sommer find from 1974 that ‘shotcrete membrane’ $t = 30\text{mm}$ is the Q-system recommendation to be used with the conservative bolt spacing of 1m c/c, and the assumed low Q-value of 0.01.

Of course, this thin shotcrete is inadequate and would not be approved today, knowing the need for at least a minimum thickness to prevent drying out, and appreciating the obvious need of structural support capacity as well.

The authors discredit Q-classification by ignoring developments since 1974. Is this negative and outdated application of the 1974 Q-system paper given to WBI course participants, promoting their FEM and ‘disqualifying’ rock mass classification?

WBI is seemingly without interest or understanding of these ‘competing’ methods. Many in the tunnelling profession have knowledge of FEM and joint elements, and shotcrete loading and bolt-loading studies. Why do WBI personnel have so little knowledge of modern classification methods that they cannot present a valid critique?

Nick Barton is principal at Norway-based Nick Barton & Associates



350
Mine sites worldwide

8
Ways to increase productivity and safety

5
Advanced communication & safety Solutions

1
Unbeatable supplier

It's easy to see why Mine Radio Systems are found in hundreds of mines around the world. Nothing is as rugged, reliable and responsive. Better still, you can expect a custom solution, featuring the right combination of two-way voice communication, video, automated equipment control, high-speed data transfer, underground internet capability or emergency evacuation.

Get started today by visiting our online resource centre for the latest information on the many ways MRS solutions can improve the safety and productivity of your mining operations.

MRS
Underground Intelligence
ISO 9001 REGISTERED

Mine Radio Systems Inc
www.mineradio.com