Société Internationale de Mécanique des Roches

INTERNATIONAL SOCIETY FOR ROCK MECHANICS

Internationale Gesellschaft für Felsmechanik

NEWS JOURNAL

Members of the new ISRM Board and the Secretariat pause together at the 10th International Congress, September 2003.

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All Corporate Members of the ISRM are listed in every issue of the News Journal, under headings that describe their main activities. If you wish to be listed under another category (or categories) please contact the editor.

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ISRM Homepage

http://www.isrm/net
http://www.lnec.pt/ISRM/

Back issues ($8) are available from the Secretariat.

Rocha Medal

A Bronze Medal and cash prize has been awarded annually since 1982 by the ISRM to honour the memory of Past President Manuel Rocha and to recognize outstanding young researchers in the field of Rock Mechanics.

The award shall be for an outstanding doctoral thesis in rock mechanics or rock engineering. The thesis must have qualified the candidate for a doctorate or the equivalent. To be considered for the award, a candidate must be nominated within two years of the date of the official doctoral degree certificate. The nomination should be submitted to the appropriate ISRM Regional Vice-President by registered letter, and may be presented by the nominee, the nominee's National Group or some other person or organization acquainted with the nominee's work. The nomination should include the following supporting information:

- *A one page curriculum vitae*, including name, nationality, nominee's place & date of birth; position, address, telephone & fax numbers;
- *A thesis summary* in one of the official languages of the Society, preferably English, of about 5,000 words, detailed enough to convey the full impact of the thesis, and accompanied by selected tables and figures, with headings and captions also in English;
- *One copy of the complete thesis* and *one copy of the doctoral degree certificate*;
- *A letter of copyright release*, allowing the ISRM to make copies for review & selection purposes only.

Nominations for the 2005 Rocha Medal must be received by 31 December 2004.

Supplementary details of the selection procedure, conferring of the award, etc., are provided in ISRM By-Law No. 7, found on pages 30–31 of the ISRM Directory for 2000. National Groups and Corresponding Members will be officially reminded by the Secretariat as the deadline approaches, but are encouraged to consider possible nominees and to recommend names to the appropriate ISRM Regional Vice-President as early as possible.

Message from the ISRM President

Dear Colleague,

It is now already more than four months since the Congress in Sandton, South Africa. I think it is important now to look at what has been done in that time and where we hope to go in the next few months.

Board and Council meetings take place at the times and venues of our international symposia. This means that there are not necessarily convenient 12-month periods between those meetings, which is demonstrated by our current situation: the next meetings will take place in November 2004 in Kyoto, followed by the meetings in May 2005 in Brno. The first period is 14 months, followed by one of 6 months. This means that we have to communicate in a different manner if we want to be effective.

Your Board has taken the electronic route, where a number of decisions have been taken by means of electronic debate (in a nutshell, "round-robbining" e-mails!). This is not quite as good as meeting face to face, but it is better than sitting back and waiting for the next meeting.

What has been achieved is that the Conference in Moscow in January 2005 (a joint conference with the ACUUS — Association for the Construction and Use of Underground Space) has been approved as a Regional Conference of the ISRM. We hope to use that conference to improve our level of contact with potential members from Russia and surroundings. So, if you are in the area, please support this event!

Also, have a look at the "Coming Events" column and where possible, support our regional conferences. Anyone for Rio in June? If you can make it there, why not? You will be in good company. Our Sister Societies will also be there. Our South American colleagues also need our support, let us give it to them!

We formulated a policy position with regard to collaboration with our Sister Societies, the ISSMGE and IAEG. In a nutshell, this comes down to a serious desire for better cooperation than in the past, but with the important proviso of the retention of our identity.

In January, there was a meeting of the three Presidents in Lisboa. This was conducted in a spirit of goodwill and mutual respect. Each of the three societies nominated three members to a Joint Task Force, to be guided by Terms of Reference drawn up by the Presidents (see our Website for details).Personally, I am optimistic that the outcome of this joint effort will be positive. The next meeting of the Presidents has been scheduled for May 2004 and we hope to have a final recommendation with regard to a structure for collaboration by the end of 2004. Our task team consists of Marc Panet, Claus Erichson and Luis e Sousa.

We have started a Board debate on the issue of assistance to the small National Groups and without pre-empting the outcome, I believe that we will have a sound solution on the table. Watch this space! The ISRM needs to be financially secure to ensure our continued existence, but we do not have an aim to make profits out of small groups.

If you visit our Website regularly, you will have noticed that some improvements have already been made. More is on the way. Our Secretary-General, Luis Lamas, deserves a lot of credit for his efforts to date and we are now ready to evaluate proposals from professional website creators and administrators to finalise the work and put us squarely in the 21st century.

In reading this, you are already aware of the implementation of one our most important Council decisions in September, which is the electronic distribution of the *News Journal*. How do you experience this? Let us know.

Warm greetings,

— Nielen van der Merwe

ISRM Membership and Address Changes Form

ISRM Membership

Are you a member of ISRM? If not, here is an easy way to join.

Individual Membership For just US $25 you and/or your colleagues can receive a one-year Introductory membership which allows you to buy ISRM goods, attend ISRM symposia, and receive the ISRM Directory and the ISRM *News Journal*. Next year you will automatically receive a renewal notice from your ISRM National Group, if one exists, or from the ISRM Secretariat in Lisbon.

Corporate membership ($200/year) provides your organization with up to three yellow-pages listings of your services or products in the ISRM Directory, with access for advertising to a select international market of more than 6,000 rock engineers and scientists.

Please complete the order form below and mail or fax it, together with your payment, to:

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To order ISRM Goods please see our website: http://www.isrm.net or contact the Secretariat (Tel: 351.21.844.3419, Fax: 351.21.844.3021, Email: isrm@lnec.pt).

JTC1 ~ Joint Technical Committee on Landslides and Engineered Slopes

by Robin Fell

1. Terms of Reference

Discussing, advancing and developing the science and engineering of landslides and engineered soil and rock slopes.

Encouraging the collaboration of those who practise in soil mechanics, rock mechanics, engineering geology, mining engineering, geomorphology and geography; as applied to landslides in natural and engineered slopes.

Fostering and organising Conferences, Symposia and Workshops, including the International Symposia on Landslides, which are held at four year intervals.

Contributing to the International Congresses/and Conferences of the ISSMGE, IAEG and ISRM.

Fostering the development, and implementation into the community, landslide hazard identification, monitoring, modelling, risk assessment techniques, risk tolerance criteria, and landslide risk management.

Fostering the organisation of training schools, and preparation of guidelines, and codes of good practice to allow the transfer and implementation into general practice of new developments.

2. Activities in Period 2001 to 29.4.2003

In this period we have:

(a) Established the committee membership. Details are attached.

(b) Determined on terms of reference and had these agreed to by ISSMGE, ISRM, IAEG.

(c) Determined the themes and invited speakers for the ISL 2004, to be held in Rio de Janeiro.

(d) Discussed our future work and plans.

(e) Organised our first formal committee meeting to be held in Naples on 11th May 2003.

3. Progress/Experience With Web Based Communication Platform

We do not use the ISSMGE platform. However we do all our communication via the web.

4. Future Planned Activities

These are to be determined at our meeting on 11 May, but are likely to include:

(a) ISL 2004 in Rio de Janeiro, June 2004.

(b) An International Conference on Landslide Hazard Zoning, and Risk Assessment, this will involve a structured set of keynote papers so the proceedings become the preferred text on the subject. This will be held in 2005 or 2006, probably in France or Italy.

We are communicating with TC32 in respect to this Conference

(c) Workshop on very large landslides. We may organise a 20-30 person workshop to bring together researchers in this area.

(d) Training courses for young professionals and/or developing countries — we may arrange this.

5. Publications

The proceedings of ISL 2004 will be published by Balkema, as would any Landslide Risk Assessment Conference Proceedings.

6. Planned Publication for ICSMGE Osaka 2005

We have nothing planned at this stage. I did ask Professor Taylor at one stage what was proposed for Osaka and at that time he did not know. Please advise me as soon as possible what opportunities exist.

Chairman: Robin Fell, r.fell@unsw.edu.au
Secretary: Kurt Douglas, k.Douglas@unsw.edu.au

Reports from the ISRM Vice Presidents

Vice-President for Australasia

Associate Professor Chris Haberfield
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September 2003 ~ Introduction

This report covers the activities of the Australian Geomechanics and New Zealand Geotechnical Societies for 2003. Both societies aim to foster all areas of geomechanics with the majority of activities including input from rock mechanics, soil mechanics and engineering geology.

AUSTRALIAN GEOMECHANICS SOCIETY

AGS membership has remained steady at about 950. The AGS offers free membership to all undergraduate students, and a reduced rate for postgraduate students. This provides valuable support and networking opportunities for young geotechnical engineers.

Australian Geomechanics, is being published four times a year and contains excellent technical papers. The current issue (Vol 38 No 3, September 2003) contains the proceedings for the Engineering Geology of Perth, which has being organised by the Western Australia Chapter. These proceedings will continue in the December issue (V38N4).

The 2-CD set of 64 past issues of *Australian Geomechanics* (from G1 in 1971 to V38N1 in March 2003) was distributed to members with the June issue of the journal (V38N2).

A recent addition to the GAS website is that of the AGS Shop. Copies of the Proceedings of GeoEng2000 and GeoEnvironment2001, as well as additional copies of the 2-CD collection of Australian Geomechanics are available for purchase.

Up-to-date activities of our society, at national and most chapter levels, are presented on our website.

The second Young Geotechnical Engineers (YGP) International Conference was held in Mamaia, Romania from 6-11 September 2003. Chris Bozinovski (AGS - Don Douglas Youth Overseas Fellowship winner), Susan Gourvenec and Jim Finlayson represented AGS at the conference. Initial response from the attendees is that the conference was a success, both technically and socially.

Planning has continued for the next ANZ YGP Conference in Brisbane in July 2004. Website: www.6thygpc.com

AGS members continue to play an important role in Joint Technical Committee (JTC1 Landslides). The last committee meeting was held in Naples in May. The JTC1 webpage is hosted by the ISSMGE website [www.issmge.org] which contains terms of reference as well as key references on landsliding. Planning includes: ISL 2004 in Rio de Janeiro (June 2004); landslide zoning, assessment and management in Vancouver in May 2005 (hosted by the Canadian Geotech Society) with the published proceedings to be a recognised as the authoritative text on the subject; workshop on velocity of large landslides in April or May 2006 in Italy; workshop on travel distance and velocity modelling (planning stage); and draft invitation to host ISL 2008 produced (proposal deadline May 2004).

AGS currently has representation by 10 members on 6 Standards Australia committees. Standards Australia is seeking AGS representation on another 4 committees.

The Jaeger Medal has been awarded to Prof Ted Brown in recognition of his lifetime commitment to advances in rock mechanics research and application. Ted will be presenting one of the keynote addresses at the 9th ANZ, February 2004 in Auckland. The title of Ted's paper is to be "The mechanics of discontinua: engineering in discontinuous rock masses."

The presentation of The Rankine Lecture Downunder has been delayed. The Lecture will be planned for 2004, subject to David Potts' health.

Dr Tony Meyers will act as National Committee liaison with the current ISRM VP for Australia, Dr John St. George.

Prof Harry Poulos, Rankine Lecturer, ISSMGE VP "at large" and 8th Casagrande Lecturer, was awarded an Australian Centenary Medal in recognition of "service to Australian society and science in geotechnical engineering"î and was recipient of the Civil Engineer of the Year award from the Civil College of Engineers Australia in recognition of his "impressive international profile and contribution as an eminent academic and an outstanding business leader."

NEW ZEALAND GEOTECHNCAL SOCIETY

Activities Since August 2002:

The 9th ANZ Conference, "To the eNZ of the Earth," is planned for 8-11 February 2004 in Auckland. 175 abstracts have been received and 131 papers have resulted. Sponsorship of $34k is in place. Keynote address will be by Geoffery Martin of University of Southern California, whilst the NZ Geomechanics Lecture (Laurie Wesley) and the Jaeger Award lecture (Ted Brown) will also be presented at the conference. The call for conference registration is due at the end of October. Successful branch meetings in 5 branches around the country.

The Society has working party's currently active on the following issues:

- Section 36 of the Building Act
- Expansive Soils

• Draft Standard DZ 4404

The NZ Guidelines for Soil and rock Description is currently under revision.

A Guideline for the Hand vane has been completed and issued.

Successfully held the 16th NZ Geotechnical Society Symposium in Tauranga in March 2003. It was well attended by over 170 delegates. Prof. Kenji Ishihara was the keynote speaker for the conference.

Prof. Ishihara also spoke at the Auckland and Christchurch branches of the Society whilst in the country.

Workshops on Soil and rock description, Engineering geology, and Serviceability limit state designs were held in conjunction with the workshop

Other visiting international speakers has included Prof. Idriss, John Turner and Max Ervin.

The Societies web page continues to be developed. It now includes a employment opportunity section and the contents pages from The NZ Geomechanics News are also being added. (www.nzgeotechsoc.org.nz)

2002 Geomechanics Awards was won by Dr Warwick Prebble for his keynote lecture 'Hazardous Terrain — An Engineering Geological Perspective."

Student prize competitions were held in Christchurch and Auckland and awards were made to each of the winners.

The NZ Geomechanics News was published in December 2002 and is due to be published in June 2003.

The proceedings of the 16th NZ Geotechnical Society Symposium in Tauranga have been published.

Proposed Activities for 2003-2004

Activities in the 5 branches will continue.

Planning is well underway for the 9th ANZ conference to be held in Auckland in February 2004. Sponsors are about to be approached. Prof. Geoff Martin is confirmed as a keynote speaker.

A new working group on Ground anchors is likely to be formed.

Completion of the Soil and Rock Description Guidelines

REPORT OF THE ISRM VICE-PRESIDENT FOR EUROPE ON THE YEAR 2002

by Pekka Sarkka

Espoo 3 September 2003

The region Europe was in 2002 by far the largest of the Regions of ISRM. It had in the end of the year altogether 23 National Groups, 49% of ISRM National Groups. Discussions were carried out with Estonia on a possible formation of a National Group.

The number of members in the Region was at the end of the year 2595, which is 56% of ISRM members. The number has been quite stable, new growth should be created preferably through affiliation of new National Groups.

The ISRM International Symposium, EUROCK 2002, was arranged by the ISRM NG Portugal in Funchal, Madeira. It got some 300 participants.

The National Groups were arranging altogether some 20 National Symposia. The most active were France, Germany, Italy and Switzerland, all with at least tree Symposia. The Vice-President visited several of the groups, and participated in the Annual Meetings of the National Groups of Finland and Sweden.

The status of ISRM Regional Symposium for 2003 was granted to three Symposia on the Region Europe. They will be held in Nancy, France, Trondheim, Norway, and Stockholm, Sweden.

Commission on Application of Geophysics to Rock Engineering

by Koichi Sassa

The working group "Standardization of Geophysical Methods for Rock Engineering" in the commission completed "the Suggested Methods for Land Geophysics in Rock Engineering." And the working group "Estimating Primary State of Stress in Rock Mass using Acoustic Emission Technique" in the commission completed "Suggested Method for in-situ Rock Stress Estimation from a Rock Core using Acoustic Emission Technique."

These two drafts made by the respective working group had been approved by the ISRM Commission on Application of Geophysics to Rock Engineering, and also had been approved by ISRM Vice-President for Asia before ISRM 2003 Council Meeting on 7th September 2003. Therefore, these two suggested methods satisfied the ISRM By-Law Number 3 clause 9 for publication as ISRM Suggested Methods.

Then, these two suggested methods will be published as ISRM suggested methods shortly.

The commission terminated at the time of the ISRM 10th Congress in South Africa in September 2003. But, Mr. President, Professor Nielen van der Merwe, had re-appointed this commission immediately for the term of this Board.

The commission is now planning to hold the 6th International Workshop on the Application of Geophysics to Rock Engineering in conjunction with 2004 ISRM International Symposium, namely, the 3rd Asian Rock Mechanics Symposium (http://lakers.kuciv.kyoto-u.ac.jp/~arms2004/). The 6th International Workshop will be held on Monday, 29 November 2003 at the same venue as the 2004 ISRM International Symposium. The detailed information will be shown in the web page of the commission (http://web.kyoto-inet.or.jp/people/sassa/).

ISRM Board Meeting, September 2003, 10th ISRM Congress in Sandton, South Africa

News From The Board

The ISRM Board met at the Convention Centre in Sandton, South Africa on 6 September 2003. The meeting took place in conjunction with the 10th ISRM International Congress.

The meeting chaired by the President of the ISRM, Prof. Marc Panet, was attended by all the Vice Presidents of the respective geographical areas except Vice President for South America.

Matters as finances, budget for 2004, progress in the organisation of the 11th Congress to be held in Portugal in 2007, selection of Symposia to be endorsed by the ISRM, activity of ISRM Commissions and of the Interest Groups, ISRM *News Journal*, as well as other matters of interest to the Society, were dealt with. An action plan for improving the ISRM activity and raising membership was considered, the idea of creating a new Website for the Society under a new concept of a Communication Platform to be developed and implemented so as to enable greater benefits and lower expenses having been introduced. On this basis the following three motions were approved by the Board:

The main method of future communication between the ISRM and its members will be electronic, including:

i) development of an interactive website;

ii) distribution of the *News Journal*;

iii) availability of abstracts of all ISRM sponsored conferences, commission and interest group reports.

The Secretariat is instructed to find an appropriate IT service provider within easy access, but preferably within Lisbon, Portugal, for the creation and maintenance of the new ISRM website.

Publication of the ISRM Directory in paper form will be discontinued until such time as it can be published in electronic form and the legal issues can be resolved.

Rocha Medal 2004

The Board, acting as the Rocha Medal Award Committee, selected the prize-winning Ph.D. thesis for 2004 from among the seven outstanding short-listed theses for that year. The winning thesis "Shear Strength of Rock Joints based on the Quantified Surface Description" was submitted by Dr Giovanni Grasselli and had been presented in 2001 to the Civil Engineering Department of the EPF Lausanne, Switzerland. The award will be conferred at the ISRM International Symposium "Contribution of Rock Mechanics to the New Century" (3rd ARMS 2004) to be held in Kyoto, Japan from 2004 November 30 to December 2.

ISRM COUNCIL MEETING 2003

The International Society for Rock Mechanics held its Council meeting in Sandton, Johannesburg,

South Africa, in conjunction with its 10th International Congress, organised by the South African National Institute of Rock Engineering (SANIRE). In the Council meeting 30 of the 46 National Groups were represented.

Accounts of 2002 and Budget for 2004

The ISRM accounts of 2002 and the Budget for 2004 were unanimously approved. A provision for membership initiatives was included in the Budget for 2004, which shall be used in order to improve the services provided by ISRM to its members.

Proposed change of the name of ISRM

The proposal submitted by the National Group of China to change the name of ISRM to International Society for Rock Mechanics and Rock Engineering, with the acronym ISRME, was presented and discussed. The proposal was voted by secret ballot and was not approved. The name and acronym of the Society remain unchanged.

ISRM Sponsored meetings

The following list of conferences sponsored by the ISRM was presented:

- 2003 October 06-08, Trondheim, Norway — The 6th International Conference on Analysis of Discontinuous Deformation, ISRM Regional Symposium.
- 2003 October 13-15, Stockholm, Sweden — International Conference on Coupled T-H-M-C Processes in Geosystems: Fundamentals, Modelling, Experiments and Applications: ISRM Regional Symposium.
- 2004 May 18-21, Three Gorges Project Site, China — The International Symposium on Rock Mechanics (SINOROCK - 2004): approved by the Board, in Sandton, as an ISRM Regional Symposium.
- 2004 November 30–December 2, Kyoto, Japan — International Symposium on the Contribution of Rock Mechanics to the New Century (3rd ARMS): the 2004 ISRM International Symposium, where the ISRM Council and Board meetings will take place.
- 2005 May 18-20, Brno, Czech Republic — International Symposium on Impacts of the Human Activity on the Geological Environment: approved by the Council, in Sandton, as the 2005 ISRM International Symposium.
- 2007 July, Lisbon, Portugal — The Second Half Century of Rock Mechanics: the 11th ISRM Congress.

A proposal was received from the National Group of Singapore to host the 2006 ISRM International Symposium. This issue will be decided in the Council meeting in Kyoto, in 2004.

Commissions

Reports were presented by the following Commissions:

- Application of Geophysics to Rock Engineering. Commission on Testing Methods.
- Joint Technical Committee of the ISRM, ISSMGE and IAEG on Landslides and Engineered Slopes (JTC1)
- Prof. Wulf Schubert presented the work of a Joint European Working Group on Professional Tasks, Responsibilities and Cooperation in Ground Engineering.

Cooperation with Sister Societies

The President of ISRM reported on the meetings that took place during last year between the Presidents of the three sister Societies (ISRM, ISSMGE and IAEG), which are planed to take place twice a year. In these meetings the creation of a federation of geotechnical societies was the main topic discussed. Creation of the federation would foster collaboration between the Societies, but each Society would keep its autonomy. As an example of the benefits of this collaboration he mentioned the creation of joint technical committees, such as the one already working on landslides and engineered slopes, and of the Joint European Working Group on Professional Tasks, Responsibilities and Cooperation in Ground Engineering.

A working group is being formed with three representatives of each society, in order to present a proposal to the three societies regarding the format of the future federation.

New Board (2003-2007)

Following the election, in 2001, of Prof. Nielen van der Merwe as President the Board of the ISRM for the term 2003-2007, the Council elected the following regional Vice Presidents:

Africa: Mr. Martin Pretorius (NG South Africa)

Asia: Prof. Zhao Jian (NG Singapore)

Australasia: Prof. John St. George (NG New Zealand)

Europe: Dr. Claus Erichsen (NG Germany)

North America: Prof. François Heuzé (NG USA)

South America: Dr. Eda Quadros (NG Brazil).

The President chose **Prof. Qian Qihu** of China and **Prof. Luìs Sousa** of Portugal as Vice Presidents-at-Large and the Vice President for Europe, **Dr. Erichsen,** was selected as First Vice President.

NATIONAL GROUP NEWS

Poland

The Polish Society for Rock Mechanics elected a new Board in June 2003, which is composed of the following members: Prof. Bernard Drzezla, President; Dr. Marek Kwasniewski, Vice President; Prof. Jan Zych, Secretary; Dr. Edmund Zastawny, Treasurer; Prof. Jerzy Gustkiewicz, Honorary President; Prof. Juzef Dubinski, Prof. Joanna Pininska, Prof. Jan Walaszczyk, and Prof. Waclaw Zuberek, Members.

Failure Around Tunnels and Boreholes and Other Problems in Rock Mechanics

Letter to the ISRM News Journal
from Nick Barton
7 October 2003

Introduction

At the recent 10th ISRM Congress held in South Africa, thanks to a well organized and different from normal format, there was ample room for discussion and numerous points of view could be expressed. The dominant "workshop format" with 5 minute presentations was an excellent "innovation" for ISRM — first experienced by the undersigned in an even better format, in an unforgettable U.S. Symposium in Minnesota in 1976—where 2 hours of prepared and spontaneous discussions of a few minutes each were presented within each main theme.

Congresses have more delegates these days, and multi-sessioning is unfortunately the inevitable result — making choice of session a major headache, as there is so much of interest. This was certainly true of the 10th ISRM Congress.

A preliminary discussion of brittle failure

Thanks to sterling work by workshop coordinators in South Africa, many of the topics for discussion were thought provoking and extremely relevant to the further development of our subject. Both in the "Rock Fracture" and "Numerical Modelling" workshops, the topics of failure modes arose — yet again — sandwiched between, by chance, a very topical plenary presentation on "stress-strength" induced failure mode observations when excavating the Lötschberg Tunnel — specifically when TBM tunnelling from the Steg portal (Rojat et al. 2003).

The depths of the "dog-ear" type failures — at 3 and 9 o'clock due to the vertical principal stress, compared favourably with a semi-empirical model (Kaiser et al. 2000) involving the ratio of σ_{max}/σ_c, where as usual, $\sigma_{max} = 3\sigma_1\text{-}\sigma_3$. Continuum FEM modelling using a Hoek-Brown failure criterion, reportedly gave a degree of "match" to the depth-of-failure observations in the tunnel, and to the empirical model ***if*** a rule-of-thumb was used that the "damage limit" is reached when the contours of the ratio of principal stress difference ($\sigma_1\text{-}\sigma_3$) to uniaxial strength (σ_c), are of the order of 0.33 (as suggested by Martin et al. 1999).

It has long been known that brittle failure around tunnels initiates when the ratio of stress to strength is a certain ***fraction*** of 1.0, whether the "stress" term is defined as σ_1, or $\sigma_1\text{-}\sigma_3$, or σ_θ the maximum tangential stress. Two of these three ratios have been important components of the Q-system too, in deciding upon appropriate SRF values for selecting support for stress-slabbing problems in numerous deep tunnels in Norway and elsewhere.

It is perhaps long overdue that we acknowledge that continuum models, with conventional soil mechanics derived strength criteria, are missing the realities of rock failure, which by the nature of intact rock and failed rock can be considered to occur perhaps in two parts — breakage of cohesion (localization) at small strain and mobilization of friction at larger strain. A Mohr Coulomb type of law may work well for a material that is already "particulate," but perhaps not very well where significant "multi-megaPascal" breakage is to occur, despite the presence of some jointing.

There are some very encouraging recent efforts—and achievements—in modelling the reality of failure around excavations, using for example, *cohesion softening* and *frictional strengthening* devices in continuum codes such as FLAC, and *"stress corrosion"* devices in particulate PFC models. Cundall, Diederichs, Kaiser and Martin and co-workers, Hajiabdolmajid, and Christine Detournay are among the growing number of prominent names in this new field of realism. There are also several other innovations in modelling, such as use of the *tensile strain criterion* of Stacey, the linear elastic and time-dependent *fracture mechanics* methods of Baotang Shen and co-workers in FRACOD, the use of tessellation patterns in displacement discontinuity models by Napier,and the recent *elastic-brittle plastic elemental degradation* modelling reported by Fang and Harrison. Each seem to be producing quite realistic models of rock failure processes, such as pillar failures and borehole and tunnel failures — without needing any more, to choose a contour of "stress/strength" where failure is "anticipated."

At this same 2003 ISRM Congress, Stacey presented a very thought-provoking discussion on how small the above stress/strength ***fraction*** can be at failure, in many different practical cases, thus emphasising the need for improved understanding and modelling of *relevant* failure processes. (Stacey and Yathavan, 2003.)

Modelling failure with continuum models and conventional failure criteria

A carefully excavated and well documented case record—the AECL-URL *line-drilled* test tunnel—with its classic 11 o'clock and 5 o'clock break-outs, has been one of the favourite objects of modelling, as illustrated in Figure 1, which is a composite of models used in a recent Martin et al. 2002 review of brittle failure modelling made for SKB in Sweden.

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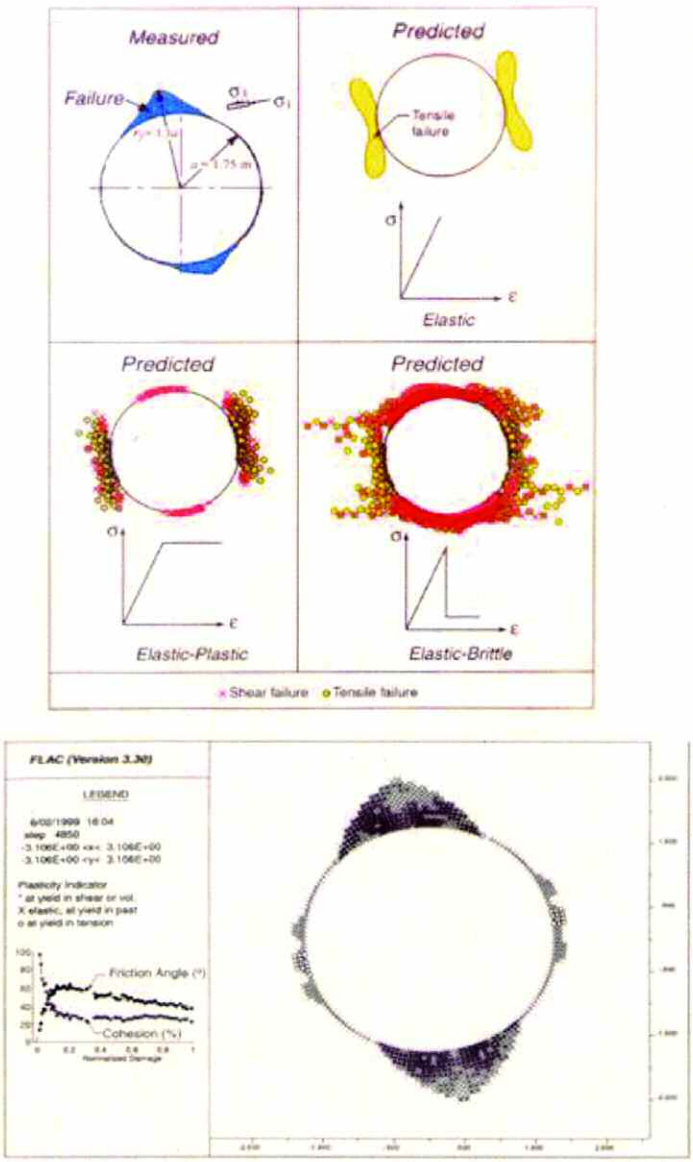

Figure 1. Three attempts to model the URL line-drilled tunnel break-out pattern with PHASES and Hoek Brown failure criteria, and an alternative cohesion softening and friction mobilization routine in FLAC. (from SKB review by Martin et al. 2002).

Seeing for the first time the serious lack of reality actually achieved by the conventional failure criteria (elastic, elastic-plastic, elastic-brittle) illustrated in this figure was frankly a shocking experience. These failure modelling efforts contrast negatively with the fascinating degree of reality achieved by Diederichs, using cohesion softening and friction mobilization, in a different continuum code, as shown at the bottom of the same figure. If this could be automated it would be excellent.

Since continuum models with conventional failure criteria (Mohr Coulomb or Hoek and Brown) apparently have such difficulty to model the "main event" that they are designed to model—namely ***failure,*** why are we with such confidence describing in our reports, papers and tribunals—"the onset of plastic behaviour," the "plastic zone," the "area (volume) requiring rock bolts," "the depth of potential failure" etc.?

The answer should surely be that we must stop, and re-evaluate the actual situation of failure in rock—as opposed to an already particulate material like sand. Are we not misleading ourselves and others by these continuum-based assessments of instability, when the failure criteria themselves are not apparently relevant to the special circumstances of failure of previously intact, brittle material?

Broadening the range of failure mode types

In Table 1, a brief synopsis of failure mode descriptions (left column), and likely modes of behaviour (right column) is given for four broad classes of tunnel failure and deformation. The suggested classes are:

Table 1

Failure modes typical in tunnels and boreholes

	Description	Mode of behaviour
1	Hard, massive, brittle rocks that dilate during failure even when stresses are high. Stress-induced failure may be delayed as 'strength corrosion' occurs	Extension failure, thin-walled stress-slabbing, dynamic ejection, bursting. The symmetric 'dog-eared' fall-out due to the anisotropic stresses may have a 'nose'. Deformations can be large.
2	Hard or medium hard, bedded and jointed rock that can shear and dilate along structural planes, while under moderate to high stress levels	Anisotropic response. Shear stress dissipates by slight shear on bedding planes and joints. Deformations are moderate. Block falls can occur.
3	Soft, massive, non-brittle rocks that may, or may not dilate during shear failure. Typical for young e.g. Tertiary rocks such as the mudstones and siltstones in Japan	Failure may occur by log-spiral shear development and tangential strain Radial deformations are large, and pressure on support is high. (Twin tunnels need pillars 4 to 5 times their span c.f. Japan, Taiwan)
4	Very soft, plastic rocks (and clays) that contract when sheared under significant stress levels.	Post peak strength loss reaches an extreme of virtual "flow", tunnel closure can occur.

1. Hard, massive, brittle rocks
2. Hard or medium hard, bedded and/or jointed rock
3. Soft, massive, non-brittle rocks
4. Very soft, plastic rocks (and clays)

It is readily acknowledged that every tunnel engineer who was asked, might produce a different list of failure modes—and their own concepts of probable behaviours. The objective here is to achieve some logical groupings, and to stimulate discussion. More particularly the aim is to stimulate a more critical questioning of what we really mean by "plastic behaviour" or by a so-called "plastic zone." In soil it is more obvious.

In the opinion of the undersigned, there has been a certain reversal of development in some quarters, since the early days (the late sixties) when

many like Goodman and Cundall were starting to look for something more realistic than the FEM continuum model solution to rock mechanics problems. That there is a definite role for continuum modelling for scoping stress levels—*with the right deformability*—is very clear. But where are the standard models that show log-spiral failure planes, as so commonly observed in borehole stability studies of previously intact and uniform rocks or model materials? There are reasonable grounds to suspect log-spiral failure surface development in squeezing tunnels too. John Bray already had analytical solutions for log spiral localization in the sixties.

The upper pair of drawings in Figure 2 (a) are from Maury, who was responsible for an ISRM Working Party review of borehole and tunnel failure modes, some two decades ago.

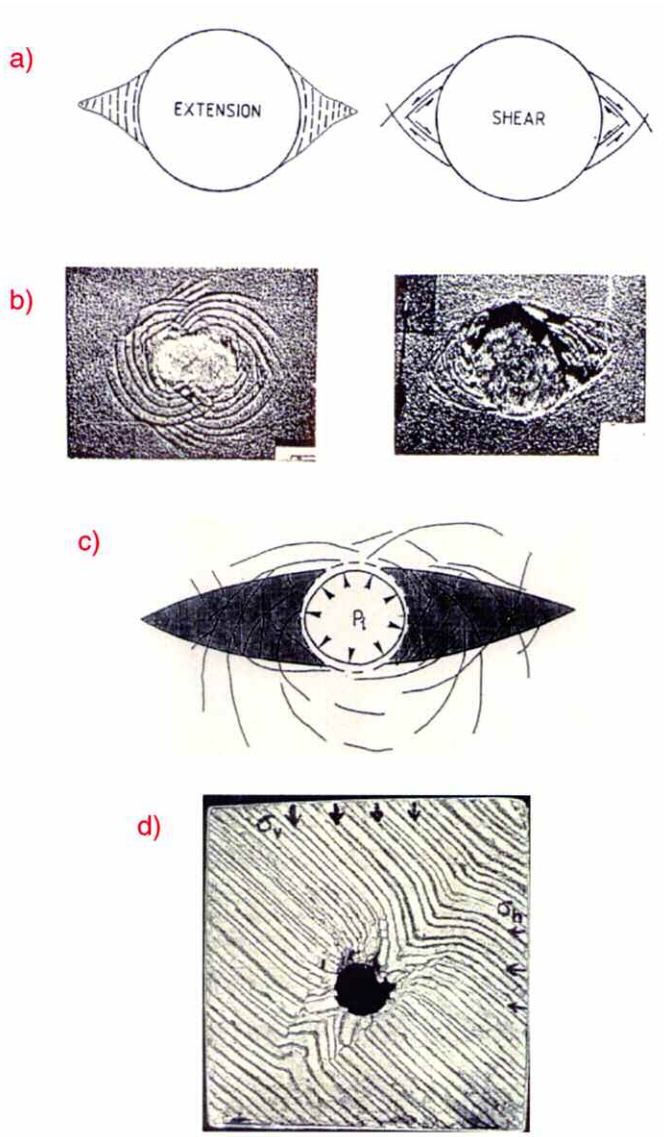

Figure 2. A selection of borehole break-out mechanisms from petroleum engineering and from related laboratory research on borehole stability and the effects of hole orientation and stress anisotropy.

The second pair (b) are from a major joint-industry borehole stability study that we conducted for several years at NGI in the late eighties. The failure modes illustrated (and numerous similar ones) were obtained by *drilling* boreholes into true-triaxial, anisotropically stressed $^1/_2$ x $^1/_2$ x $^1/_2$ m blocks of very uniform 0.5 MPa sand-"stone."

The model boreholes could be drilled in any desired direction in relation to the three, usually unequal, principal stresses. Some of the results of these studies were presented by Addis et al. 1990. Bandis, who was also a major contributor to this research, was responsible for the "bedded" model shown in (d) and (from memory) for comparing the MC elastic-plastic closed form solution shown in (c), with the rather different physical reality of log spiral surfaces.

Through the clever device of coloured, re-cemented miniature boreholes, Bandis was able to demonstrate in some preliminary, pre-instrumented model blocks of sand-"stone," that the log-spiral surfaces—which occurred without exception—were shearing by a millimetre or so, causing a pseudo *tangential* deformation, but seen first as "radial" closure. The tangential strain concept, long favoured by Aydan in Japan, has its reality in the log spiral failure mode, as also proposed by Aydan for the case of squeezing tunnels in Japan.

So the initial ***continuum*** actually becomes a ***discontinuum,*** due presumably to breakdown of cohesion and mobilization of friction along the "localization" surfaces. There were actually grounds for suspicion that in some of our "oblique to the principal stress" boreholes, a sequence of e.g., "clock-wise" oriented log-spirals sufficiently altered the redistributed stresses, that opposing (intersecting) "anti-clock-wise" log spirals then formed. There was usually an intersection of the (presumably) shear failure surfaces, but not in all cases.

In an interesting presentation by Wittke at the recent Congress, a photograph of the Yacambu Tunnel in Venezuela was shown, to demonstrate "squeezing" conditions. To the undersigned, the somewhat pointed and curved "blocks" of failed material seen in the left side of the tunnel, was a strong reminder of log-spiral-type failures, which are not usually so easy to observe in a tunnel, due to the presence of (failing/yielding) support.

Returning to Table 1 failure mode types, we may conclude that the *hard, massive, brittle rocks* (Type 1) and the *soft, massive, non-brittle rocks* (Type 3) apparently each present problems for continuum modelling—**if the models need to show the development of failure**. We should also be aware of the probable limitations of continuum modelling, when deformation modes in *hard or medium hard, bedded and/or jointed rock* (Type 2) are to

be represented **correctly,** due to the often anisotropic response caused by slip, dilation and opening (or closure) of the joints and bedding planes.

Thanks to earlier developments by Cundall, we can readily model jointing effects around tunnels. Idealized, and more realistic discontinuum 2D models, using UDEC-MC or UDEC-BB, are shown in Figure 3. We can use 3DEC-MC when the orientation of the bedding and/or jointing are creating a more obvious need for three-dimensional modelling.

The obvious relative difficulty of using these more realistic models in relation to continuum models, needs to be overcome by practitioners who are interested in realism at the local scale of tunnel, cavern or slope instability. There are unfortunately a remarkable number of colourful but unreal continuum model solutions appearing in report appendices these days.

It appears to this author that today's conventional failure criteria—partly adopted from soil mechanics, are more suitable for modelling failure (i.e., the development of a plastic zone) in *very soft, plastic rocks* (Type 4) than for modelling the more regular problems (Types 1, 2 and 3) that we usually encounter at the medium to harder ends of the typical rock mechanics and tunnel engineering spectra.

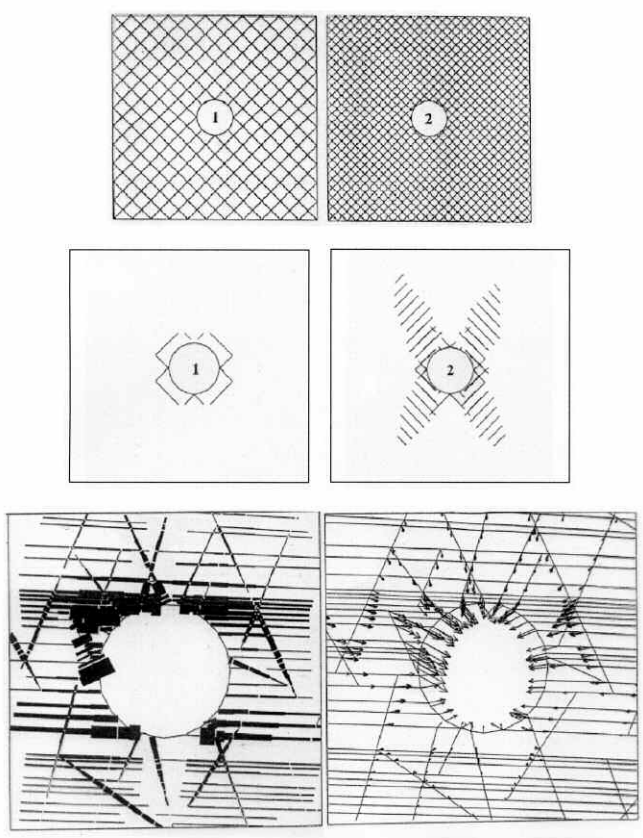

Figure 3. Examples of two idealized UDEC-MC models, and of a proposed TBM tunnel excavated in a more realistic UDEC-BB model of Interbedded sandstone and shale. Anisotropic joint shearing and deformations are occurring, due to details of the joint structure. Barton et al. 1992.

C *then* ϕ, not C *and* ϕ, and alternative sources for these estimates

When using continuum models with Mohr Coulomb or Hoek Brown failure criteria, in other words the conventional ***addition*** of cohesion and σ_n x tan ϕ (in a linear MC form or with the potential non-linear HB improvement) we are *in reality* so uncertain about the role of cohesion, of its real magnitude, and of the strain needed to gradually destroy its remaining contribution to strength, that it does not seem to make sense to use an equation as complex as the following.

$$c' = \frac{\sigma_{ci}\left[(1+2a)s+(1-a)m_b\sigma'_{3n}\right]\left(s+m_b\sigma'_{3n}\right)^{a-1}}{(1+a)(2+a)\sqrt{1+\left(6am_b\left(s+m_b\sigma'_{3n}\right)^{a-1}\right)/((1+a)(2+a))}}$$

(where $\sigma_{3n} = \sigma'_{3max}/\sigma_{ci}$, together with the usual GSI, a , s and m_b relations)

GSI is actually relatively insensitive to major changes in stability. Only a 2:1 change in magnitude in GSI is apparently needed to convert a massive bedded rock into a squeezing variety with large deformation, when using (in this case: inappropriate) isotropic continuum modelling. The relative complexity of many GSI-based parametric equations might perhaps be an indirect result of this numerical insensitivity to changed rock quality, where the one order of magnitude range of GSI is designed to cover all possible rock mass conditions. This is surely a tough proposition.

It was recently recognised that the Q_c value of rock masses (where Q_c = Q x σ_c/100) is suspiciously like the ***product*** of "cohesion" and "tan ϕ" (Barton, 2002). This surprising finding might have something to do twith the case record based development of Q. Shotcrete, in different thicknesses, is broadly speaking a practical surface "fix" for lack of cohesive strength, while rock bolts, with different spacings, are compensating for lack of (internal) frictional strength.

All the Q-parameters and their ratings were developed by an exhaustive trial-and-error fit to 200-plus case records, many of which were dependent on this additional/ supplemental "c and ϕ" treatment for their stability. So we may have a useful new tool for making a first estimate of the cohesive component of rock masses, without resorting to complex equations correlated to classification methods.

The alternative and preliminary estimate of rock mass "cohesion" can apparently be obtained from the regular components of Q, as follows:

$$\text{"c"} \approx \left(\frac{RQD}{J_n} \times \frac{1}{SRF} \times \frac{\sigma_c}{100}\right)$$

The following table (Table 2) demonstrates the order of magnitude of the Q_c based CC (cohesive

Table 2. Five progressively worsening rock mass qualities and some of their predicted near surface properties, including FC and CC (Barton, 2002).

RQD	J_n	J_r	J_a	J_w	SRF	Q	σ_c	Q_c	FC °	CC MPa	V_p km/s	E_{mass} GPa	L
100	2	2	1	1	1	100	100	100	63°	50	5.5	46	0.01
90	9	1	1	1	1	10	100	10	45°	10	4.5	22	0.1
60	12	1.5	2	0.66	1	2.5	50	1.2	26°	2.5	3.6	10.7	0.8
30	15	1	4	0.66	2.5	0.13	33	0.04	9°	0.26	2.1	3.5	23
10	20	1	6	0.5	5	0.008	10	.0008	5°	0.01	0.4	0.9	(?)

Note : Because RQD and Jr/Ja can be oriented properties, so too can Q and the related properties.

component) and the remaining FC (frictional component). We should hesitate to call CC and FC the "c and ϕ" of the rock mass, because we *actually have* little reason to believe that these widely different properties can be captured (or combined) in a continuum format when failure is occuring. Nor are their magnitudes actually known to any significant degree of accuracy in the case of rock masses, as opposed to intact laboratory samples, where the Hoek Brown criterion gives an excellent fit to a large data base, because of the related history of its development.

As for the case of "c and ϕ," CC and FC are likely to be mobilized at radically different levels of strain in a rock mass. It therefore makes no practical sense to "add them" in a strength criterion. ***First one, then the other*** should be the motto. But in reality there is probably a step-function (or more graduated) response from each, following some significant AE events as much of the multi-MPa cohesion is destroyed at the smaller initial strains. Shotcrete failure and rock bolt mobilization also display strain-dependent responses, hence perhaps their earlier help in giving hidden clues to CC and FC.

Some other problems requiring research and correction

Most of the older generation of rock mechanics engineers, and no doubt many of the younger, will have produced their own mental lists of "problem areas," where the available tools (models, constitutive laws, theories) apparently require some improvement. There are in fact a multitude of Ph.D. topics for the enquiring student—and plenty for the rest of us too. Here is part of a personal list which hopefully will be added to by others.

1. Direct shear tests on joints are normally performed by loading to the assumed ranges of effective normal stress in the future rock structure (slope, foundation, etc.) and then commencing shear. The reality may often be an *unloading* from a previously higher effective normal stress, followed by shear (for example when excavating a rock slope). "Over-closed" shear testing on tension fractures with over-stress ratios of 1 (the conventional), 4 and 8 produced three distinct, differently inclined peak strength envelopes. (Barton, 1971).

Where does the limit of roughness prevent this "over-closure" behaviour, where the "perpendicular JRC" ceases to lock the joints in a tight embrace? Interestingly, an extreme JRC of about 25 (judging from profiles) has been found to give a tilt angle of 180° (or apparent tensile strength). When normal stresses orders of magnitude greater than 0.001MPa (from a 4cm thick tilt-test sample) are applied, the "tensile-strength-limit" for JRC obviously reduces dramatically.

2. In a related area, but now concerning the application of *thermal loading*, rough joints (e.g., JRC=10 or more) apparently exhibit more compliance due to reduced normal stiffness, when heated than when cold. This effect has been suspected for a long time—from initially confusing deformation response at the heated Climax mine-by, from changing and then hysteretic seismic velocities in Stripa heater experiments, from reduced hydraulic and physical apertures at an 8m^3 heated block test and in smaller laboratory coupled-stress-flow-temperature CSFT tests, and from different deformation response in the heated and cold sides of cross-adit plate bearing tests at Yucca Mountain. The list could be extended.

Where are our constitutive laws that acknowledge tighter mating of joints at elevated temperatures (?)—with the unfortunate converse that the roughest joints that may stay mated when cooling, due to over-closure, may cause concentration of joint opening on the less rough, and likely weaker and more permeable joints. Where is our emphasis on the often very high unloading stiffness of joints and of rock masses?

3. We have inherited much that is useful from the developers of soil mechanics, above all else the law of effective stress. But we have also inherited the classic (and probably wrong) way of transforming principal stresses on to potential failure surfaces (or to joints) initially ignor-

ing the effect of dilation on the normal stress, ***and still ignoring the effect of dilation on the shear stress***. In the latter we are in "good company."

But OC clay, compacted sands and rockfill and non-planar rock joints (and probably many failure surfaces in rock) dilate during shear at usual levels of effective normal stress. It is easy to *feel the need* to correct the normal stress for the expanding effect of dilation. But the shear stress can be larger or smaller than the classical, co-axial stress and strain based law assumes, depending on the magnitude of the angles involved. Barton, 1986, 1999.

Maybe, the correct stress transfer is obtained by adding in the current, mobilized dilation angle to the angle (β) between the major principal stress and the assumed failure plane (or mean joint plane). Strictly speaking neither the plane nor joint should be present, nor should they shear, or dilate. Do we *really* know the ultimate stability of our rockfill dams, of our arch dams founded on jointed rock abutments, of our jointed rock slopes (or our wedge-shaped blocks)?

4. Large scale structures in rock, and numerical models of heavily jointed discontinua, and physical models with thousands rather than hundreds of blocks—each show block rotation (first as kink bands) as their principal mode of deformation and failure (e.g., Ladanyi and Archambault, Barton and Hansteen, 1979 and others). This rotation may be stimulated by several factors, including the increased shear strength as block size reduces, block corner "hang-ups" due also to the partly stepped, composite surfaces of secondary and tertiary joint sets, and the more obvious relative ease (lower energy requirement) of block rotation and corner crushing, as block size reduces.

Are such rock masses more correctly modelled by continuum codes than discontinuum codes, or not? Can we talk of localization of failure in such cases? Are these the mechanisms required for successful block caving?

This leads to a final, most problematic question. What do we mean by the "Poisson ratio" of a rock mass? Physical models with hundreds or thousands of blocks, loaded biaxially, can demonstrate "lateral expansion coefficients" (perhaps a better name for discontinua?) that exceed 1.0 as shear failure is approached. To what extent are such phenomena influencing the ultimate stability of an over-stressed tunnel, cavern, rock slope or mining stope?

Conclusions

1. Continuum models with conventional Mohr Coulomb or Hoek Brown failure criteria fail to model the break-out or log-spiral failure surfaces *observed* in numerous studies of borehole failures, and *suspected* in over-stressed tunnels.
2. Recent efforts to model shear or tensile failure localization by cohesion softening, friction mobilization, stress corrosion, element degradation, tensile strain limitation, or by fracture mechanics, collectively show great promise, and herald an exciting new phase of realism in initially-a-continuum (IAC) modelling.
3. There remain numerous interesting problems to solve in rock mechanics. A whole class of these are due to the effects of loading history on joint compliance, including the effect of heating. Joint roughness effects causing hysteresis when over-closed by reducing normal stress, can potentially alter our concepts of shear strength and methods of shear strength measurement.
4. We seem to have inherited incorrect methods of principal stress transformation to inclined failure planes and joints. Co-axial stress and strain are not the reality for significant shear displacements in either compact sands, O.C. clay, rockfill or along non-planar rock joints and brittle failure surfaces in rock. The addition of the mobilized or instantaneous dilation angle in the stress transformation equation, may solve the problem of the increased normal stress and reduced **or** increased shear stress caused by dilation.
5. Block rotation is an important mechanism of failure when large numbers of blocks are present with the necessary degree of freedom for rotation, due for example, to low values of RQD/Jn. Difficulties with the definition and magnitude of "Poisson ratio" for rock masses suggest one of the reasons why continuum modelling is also a difficult proposition when failure is approached.

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Cylindrical Cavities in Creeping Strata

By Joachim Klein

Computer simulations of time-dependent problems in geotechnics are in general very complex, so that an easy result check is hardly possible. Here knowledge of the stationary asymptotic stress and strain behaviour is very helpful. Using steady-state Norton's creep law $\dot{\varepsilon}^c = \kappa \cdot \sigma^n$ the dimensionless non-linearity parameter n concerning stresses is highlighted, which also controls other creep laws. For axi-symmetrical structures closed-form solutions exist for steady-state creep and in the paper they are transformed under plane-strain conditions to infinite solids. Calculation examples of cavities in creeping strata like a borehole and a shaft as compared to published FEM results as well as measurements show the advantage of such control possibility.

Non-linear creep

Creep problems have generally been solved over the last years by sophisticated computer simulations, trying to take into account different aspects by phenomenological description (Figure 1). *Penny and Marriott 1971* (1) give an instructive survey on creep laws, demonstrating that total strains may generally be combined by elastic plus inelastic components (including plasticity, thermal effects, creep etc.). This paper will not discuss the correctness of complicated creep laws, but demonstrate that plausibility of computer results concerning cavities in creeping strata may be checked by using the elastic analogy of *Hoff 1955* (2). Focussing only on the secondary creep stage with constant creep rate as function of stress, *Norton's 1929* (3) creep law $\dot{\varepsilon}^c=\kappa\cdot\sigma^n$ can be adopted, where k is a temperature dependent viscosity parameter and n a dimensionless stress exponent. In engineering science in general

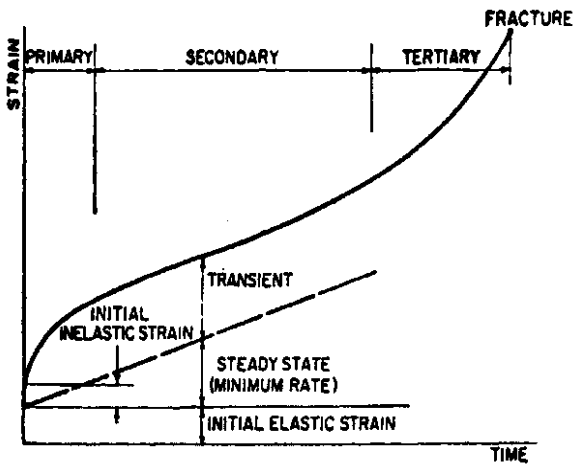

Figure 1. Creep curve with idealized sections

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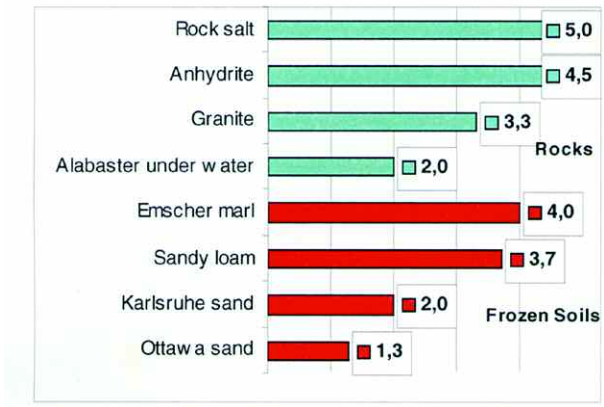

Figure 2. Non-linearity parameter n

complex stress stages are relevant and the first problem is to generalize the constitutive expressions from uni-axial to multi-axial state of stress. *Odqvist and Hult 1962* (4) propose a relationship between creep strain tensor and stress deviator tensor. With this the volume remains constant with respect to creep strains, which means incompressibility. Accordingly in creep calculations on additive hydrostatic stress situation, no change in creep rate will follow. The stress-strain law is taken as equal in tension or compression, the multi-axial relation under uni-axial condition changing into a uni-axial one. In Figure 2 typical n-parameter for different rocks and for frozen soils with similar behaviour are in addition listed.

Thick-walled cylinder

Before the stress-strain relations are examined in geomechanics, the equations for an axi-symmetrical structure under internal and external pressure, like a thick-walled hollow cylinder are highlighted. Under incompressible plane strain conditions, i.e., long pipes, *Odqvist and Hult 1962* (4), show for the w component:

$$\frac{d\dot{w}}{dr} + \frac{1}{r}\cdot\dot{w} = 0 \qquad (1)$$

from which with constant C there results $\dot{w}=C\cdot r^{-1}$. Taking account of the corresponding deviator stresses and strains the radial equilibrium can be formulated:

$$\frac{d\sigma_r}{dr} = \frac{\sigma_t - \sigma_r}{r} \qquad (2)$$

With the constants A and B the radial stress σ_r and tangential stress σ_t the following applies:

$$\sigma_r = A\cdot r^{-2/n} + B \qquad (3)$$

and

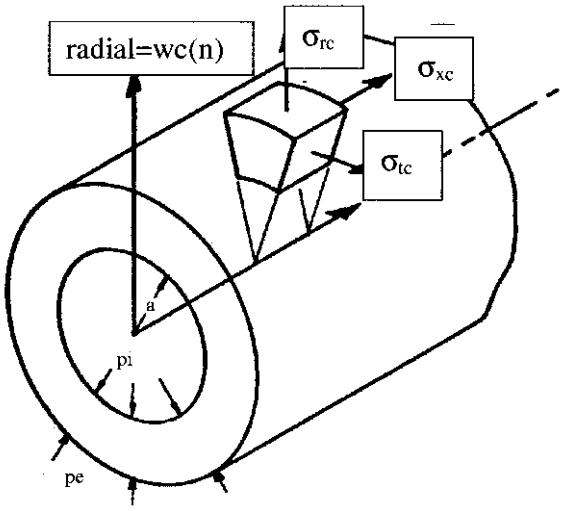

Figure 3. Cylindrical system index c with nomenclature

$$\sigma_t = A \cdot (1 - \tfrac{2}{n}) \cdot r^{-2/n} + B \qquad (4)$$

respectively (Figure 3).

The constants A and B are defined by the boundary conditions σ_r (a) = - pi (internal pressure) and σ_r (b) = - pe (external pressure). For the axial stress under these conditions the following is obtained:

$$\sigma_x = \tfrac{1}{2} \cdot (\sigma_r + \sigma_t) \qquad (5)$$

$$\sigma rc(r) := -pi \cdot \frac{r^{-\frac{2}{n}} - b^{-\frac{2}{n}}}{a^{-\frac{2}{n}} - b^{-\frac{2}{n}}} + pe \cdot \frac{r^{-\frac{2}{n}} - a^{-\frac{2}{n}}}{a^{-\frac{2}{n}} - b^{-\frac{2}{n}}}$$

$$\sigma xc(r) := -pi \cdot \left[\frac{\left(1 - \frac{1}{n}\right) \cdot r^{-\frac{2}{n}} - b^{-\frac{2}{n}}}{a^{-\frac{2}{n}} - b^{-\frac{2}{n}}} \right] + pe \cdot \left[\frac{\left(1 - \frac{1}{n}\right) \cdot r^{-\frac{2}{n}} - a^{-\frac{2}{n}}}{a^{-\frac{2}{n}} - b^{-\frac{2}{n}}} \right]$$

$$\sigma tc(r) := -pi \cdot \left[\frac{\left(1 - \frac{2}{n}\right) \cdot r^{-\frac{2}{n}} - b^{-\frac{2}{n}}}{a^{-\frac{2}{n}} - b^{-\frac{2}{n}}} \right] + pe \cdot \left[\frac{\left(1 - \frac{2}{n}\right) \cdot r^{-\frac{2}{n}} - a^{-\frac{2}{n}}}{a^{-\frac{2}{n}} - b^{-\frac{2}{n}}} \right]$$

case n=2 the tangential stress σ_t is constant along the

Usually the explicit equations for hollow cylinders under inside pressure pi are documented, extended also to outside pressure by *Klein 1978* (5) thus resulting in the equations (6, 7 and 8 with additional index c for cylinder) given above.

As documented in the literature, linear-elastic conditions n=1 yield the *Lamé* expressions for stresses in hollow cylinders, i.e., *Flügge 1962* (6). For rigid-plastic conditions n=∞ the publication of *Hill 1950* (7) is relevant.

Dimensionless consistent units are necessary when using the relationships. Of interest is the non-linearity parameter n for tangential stress σ_t, which reaches a maximum at the inside rim, if n<2, otherwise on the outside. In the case n=2 the tangential stress σ_t is constant along the cross-section.

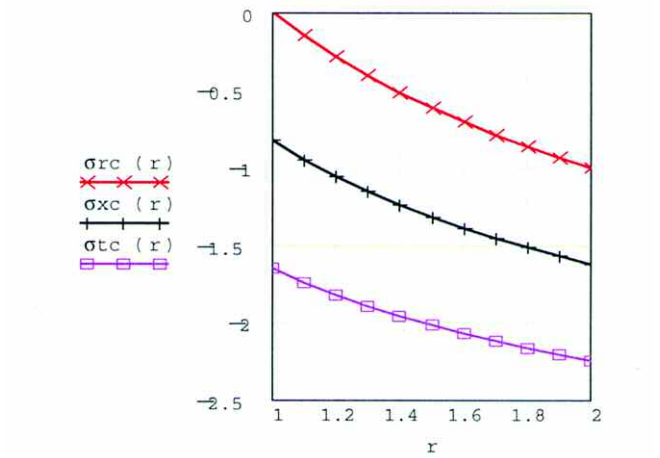

Figure 4. Radial rc, axial xc and tangential tc creep stresses for pe=1 (pi=0) in a thick-walled cylinder

In Figure 4 the stress distribution of a thick-walled hollow cylinder under outside pressure with the radius ratio b/a=2 is shown, using n=5 which *Wittke und Werfling 1999* (8) also adopt for rock-salt.

Using the tangential strain rate the radial deformation rate $\dot{w}$=wc(n) at the inner rim can be formulated with equation 9 below. In the following, wc(n) represents the stationary deformation rate, called creep-rate in the following.

$$wc(n) := \left(\frac{3^{0.5}}{2}\right)^{n+1} \cdot k \cdot a \cdot \left[\left[\frac{pi \cdot \left(\frac{2}{n}\right) \cdot a^{-\frac{2}{n}}}{\left(a^{-\frac{2}{n}} - b^{-\frac{2}{n}}\right)} \right]^n - \left[\frac{pe \cdot \left(\frac{2}{n}\right) \cdot a^{-\frac{2}{n}}}{\left(a^{-\frac{2}{n}} - b^{-\frac{2}{n}}\right)} \right]^n \right] \qquad (9)$$

Axi-symmetrical cavities

When the outer radius b → ∞ the system corresponds to a plane strain problem, which allows for geotechnical convergence solutions. *Prij & Mengelers, 1981* (9) assume for a borehole calculation (Figure 5) that in axial and lateral direction the pressure p without inside pressure is acting (case a). Here the hydrostatic pressure p of the same order

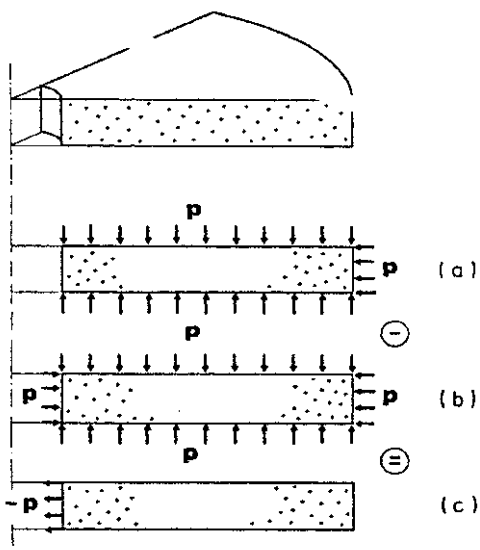

Figure 5. Calculation scheme for a borehole

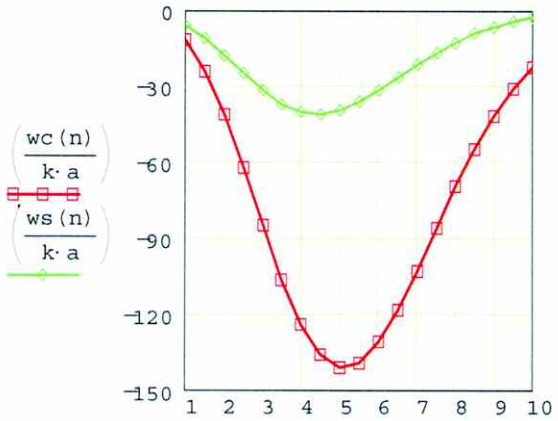

Figure 6. Creep-rates for cylindrical and spherical cavities in a stress field of p=8 MN/m² and different n

has no influence on creep (case b), and so the system can be reduced to a plane with an axi-symmetrical hole with a corresponding inside tension —p at the inside rim (case c) (see also *Borm 1988* (10)). Formally the reverse (case b)+(case c) = (case a) also applies. In this case a plane under outside pressure results in the same numerical deformation values at the inside rim, including the secondary stress state. If one focuses on the creep rate at the inside rim for cylindrical wc(n) or spherical ws(n) openings within a plane under pi → 0 and pe → p , equations 10 and 11 can be written according to Klein 2000 (11). For incompressible creep in isotropic stress fields p the stationary creep-rates can then be calculated to:

cylindrical

$$wc(n) = -\frac{\sqrt{3}}{2} \cdot k \cdot a \cdot (p \cdot \frac{\sqrt{3}}{n})^n \qquad (10$$

spherical

$$ws(n) = -\frac{1}{2} \cdot k \cdot a \cdot (p \cdot \frac{3}{2 \cdot n})^n \qquad (11)$$

In these potential creep equations the maximum as a function of n and p is of special interest. In a constant stress field of p=8 MN/m², for example,

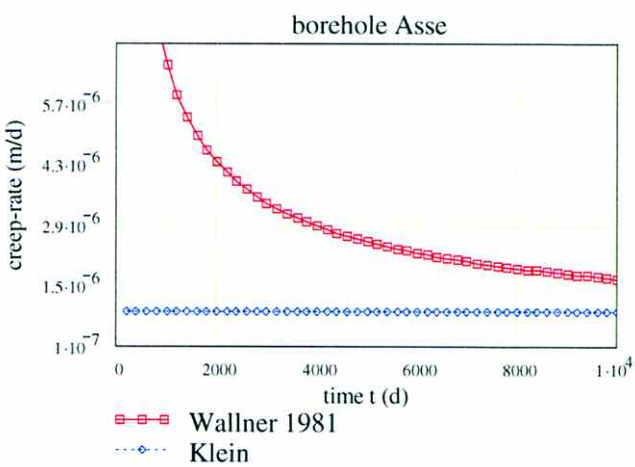

Figure 8. Radial creep-rate of a borehole in rock-salt

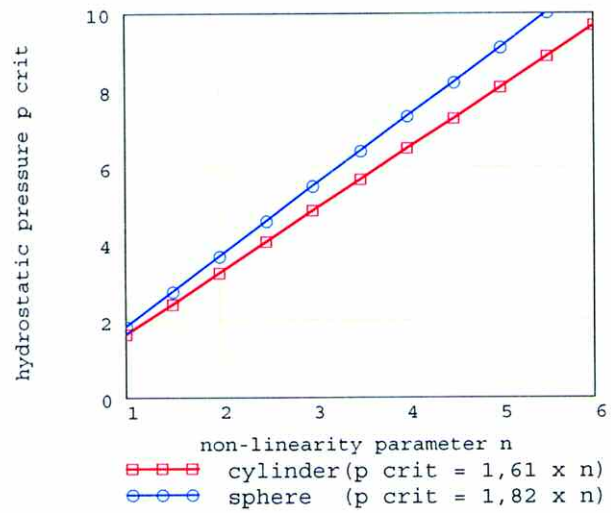

Figure 7. Dependence of hydrostatic stress field pcrit and non-linearity parameter n

(Figure 6), the creep-rates for identical *k·a* factors are shown, while n runs from 1 to 10.

It is clear that spherical openings result in smaller absolute values than cylindrical ones, but the characteristic maximum appears in combination with different non-linearity parameters n. That means every hydrostatic pressure p is combined with a critical n where the creep-rate yield a maximum. Vice-versa, every n corresponds to a critical hydrostatic pressure p_{crit}. An evaluation of the maximum of different creep-rate curves yields a statement about the critical hydrostatic stress p_{crit} as a function of the non-linearity parameter n.

In Figure 7 the n parameters run from 1 to 6 and can be extrapolated for greater n by:

cylindrical

$$p_{crit} = \frac{n}{\ln \sqrt{2 \cdot \sqrt{3}}} \qquad (12)$$

spherical

$$p_{crit} = \frac{n}{\ln \sqrt{3}} \qquad (13)$$

While in civil-engineering the choice of material can be made dependent on the allowable stresses, it is not possible in geology. The rock stratum with its material properties and typical specific n parameters cannot be changed. The only possibility is to modify the depth or dimensions of the underground opening in order to reduce the creep-rate. When applied to rock-salt with n=5 the creep-rate maximum appears at p_{crit}=8 MN/m² (Figure 6 and 7), while a spherical opening results in p_{crit}=9.1 MN/m² with identical *k·a* factors.

Case Histories

Two examples from the literature are intended to demonstrate the use of the simple equations above, to check plausibility for the stationary stage, also with respect to more sophisticated numerical model results. In both cases in-situ measurements, for the

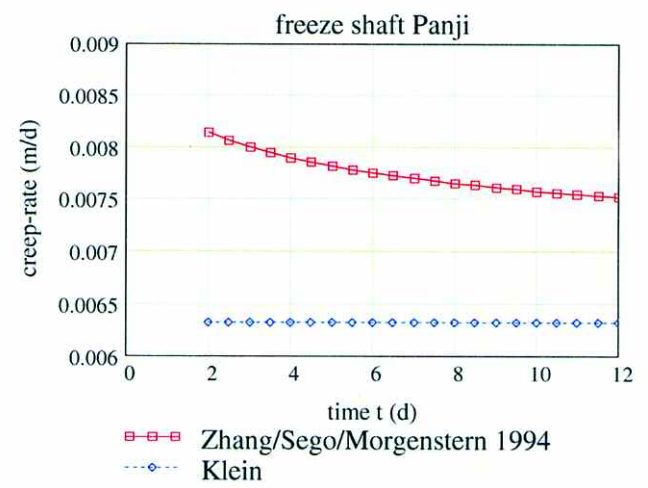

Figure 9. Radial creep-rate of a freeze-shaft during unlined sinking phase

transient stage as well, are documented in the references cited.

borehole

The complex rheological material laws of rock-salt were investigated by *Munson und Wawersik 1991* (12) and *Langer 1991* (13). Finite Element calculations were conducted for Asse repository by *Chabannes, Case, Shukla und Ellison 1981* (14) and *Wallner 1981* (15). The latter examined with the ANSALT code the convergence of a borehole with an inner radius a=0.1575m within a stress field of p=22.5 MN/m^2 with k=2.25*10^{-10} [(MN/m^2)$^{-5}$d^{-1}] and n=5. Besides *Norton's* creep characteristics the instantaneous elastic modulus E=25,000 MN/m^2 and ν=0.25 were used. As shown in Figure 8 the creep-rate after 1,000 days is still 7 times the stationary rate. By using equation 10 the answer is 8.8*10^{-7} m/d.

In the *Shaft Design Guide 1987* (16) this example is also discussed and documented, that even for long-term conditions there is still a difference of factor of 1.7 to the stationary solution.

shaft

Permafrost, i.e., frozen soil, shows similar creep characteristics to those of rock-salt, but with greater elastic strains and equivalent non-linearities published by *Klein 1985* (17). *Sego and Morgenstern* 1994 (18) analyse with the ADINA code for Panji-shaft a stress field of p=4.28 MN/m^2 with k=1*10^{-4} [(MN/m^2)$^{-2}$d^{-1}] and n=2 for an inner diameter of 2a=10.6m. Besides Norton's creep part the instantaneous elasticities are selected as E=130 MN/m^2 and ν=0.3. With the same equation 10 the stationary creep-rate of the freeze-shaft can be calculated. As can be seen in Figure 9, transient creep approaches much faster in the direction of steady state of 6.3*10^{-3} m/d than in the borehole example. The velocity reaching constant creep-rates is mostly dependent on the relation of elastic to non-elastic strains, regardless of the creep law used.

Conclusions

Even for complex computer simulations of creep problems in creeping strata, the steady-state convergence characteristics can easily estimated for axisymmetric cavities with cylindrical or spherical contours. Using *Norton's* creep law $\dot{\varepsilon}^c = k \cdot \sigma^n$ the decisive importance of the dimensionless non-linearity parameter n is demonstrated in this paper. There is an interesting correlation between maximum creep-rate and n, corresponding to a critical hydrostatic stress field p_{crit}. Under incompressible plane strain conditions the equations exhibit closed form solutions concerning stationary creep-rate for cylindrical (index c) and spherical (index s) openings in creeping strata like rock-salt or even frozen soils. The resulting stationary creep-rate is a safe lower boundary when using *Norton's* creep law approximation types. So old fundamentals may help i.e., in repository projects developed in different European countries nowadays. Friends of powerful FE-tools in particular should examine their results to give them the certainty that their transient velocity situation is always above steady-state level.

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2004, Helsinki FINLAND — 7th International Symposium on Environmental Geotechnology and Sustainable Development.

2005 January 25-28, Moscow RUSSIA – Rock Mechanics for Underground Environment. An ISRM Sponsored Regional Symposium, organised by the ISRM NG RUSSIA. Prof. Sergey A. Yufin, Center of Underground and Special Engineering, Moscow State University of Civil Engineering, Yaroslavskoye Shosse 26, 129337 Moscow, RUSSIA. Tel.: 7/095/9180543(also fax); Email: info@acuus-isrm05.ru; Website: http://www.acuus-isrm05.ru.

2005 May 18-20, Brno CZECH REPUBLIC – EUROCK 2005, the 2005 ISRM-Sponsored International Symposium, organized by the ISRM NG CZECH REPUBLIC. International Symposium on Impacts of Human Activity on the Geological Environment Dr Pavel Konecn‡, Inst. of Geonics AS CR, Studentská 1768, CZ-70800 Ostrava-Poruba, CZECH R. Tel.: (+420) 69 6979111; Fax (+420) 69 6919452; Email: konecpa@ugn.cas.cz.

2006, September 19-21, London, United KINGDOM — 10th International Congress of the International Association of Engineering Geology and the Environment. The title will be "Engineering geology of tomorrow's cities." Email: mike.rosenbaum@ntu.ac.uk

2007 July, Lisbon PORTUGAL – ISRM 11th International Congress on Rock Mechanics, organized by the Portuguese Geotechnical Society (SPG), (the ISRM NG PORTUGAL). Sociedade Portuguesa de Geotecnia, LNEC, Av. do Brasil, 101, 1700-066 Lisboa, PORTUGAL; Tel.: (+351) 218443321; Fax:: (+351) 218443021; E-mail: spg@lnec.pt; Website: http://www.isrm2007.org. 2004 May 18-21, Three Gorges Project Site CHINA - International Symposium on Rock Mechanics SINOROCK - 2004, an ISRM-Sponsored Regional Symposium, organized by the Chinese Society of Rock Mechanics and Engineering (CSRME), (the ISRM NG CHINA), the Chinese Academy of Sciences (CAS), and the International Journal of Rock Mechanics & Mining Sciences. Theme: Rock Characterization, Modelling, and Engineering Design Methods. Prof. John A. Hudson, SINOROCK, 7 The Quadrangle, Welwyn Garden City, Herts AL8 6SG, UK. Tel.: (+44) 1707 322819; Fax: (+44) 1707 375912; E-mail: sinorock@rockeng.co.uk. Prof. Feng Xia-Ting, SINOROCK, Inst. of Rock and Soil Mechanics, Xiaohongshan, Wuchang, 430071 Wuhan, CHINA PR. Tel.: (+86) 27 87218913; Fax: (+86) 27 87863386; E-mail: sinorock@dell.whrsm.ac.cn; Websites: www.sinorock2004.com, sinorock2004.com.cn.