



Bogota, D.C., February 26<sup>th</sup>, 2010

**Dr LUIS LAMAS**  
**Secretary General**  
**International Society for Rock Mechanics**  
c/o LNEC, Av. do Brasil 101,  
1700-066 Lisboa, Portugal

**Ref.: Nomination for the ISRM Leopold Müller Award 2011**

Dear Dr. Lamas:

On behalf of the Colombian Geotechnical Society (SCG-Sociedad Colombiana de Geotecnia), I am pleased to nominate **Dr. Nicholas R. Barton** as the recipient of the 2011 ISRM Leopold Müller Award for distinguished contributions to rock mechanics and rock engineering.

The following documents are enclosed, as required by ISRM ByLaw 8:

- a) An about 1000 word summary of achievements and contributions of Dr. Barton to the fields of Rock Mechanics and Rock Engineering
- b) A curriculum vitae of Dr. Nicholas Barton, including his publications.

Dr. Barton addresses are:

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Fjordveien 65c, 1363 Hovik,  
NORWAY  
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Dr. Nick Barton  
R. Miguel de Almeida Prado 20,  
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BRAZIL  
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Cordially yours,

**SOCIEDAD COLOMBIANA DE GEOTECNIA**

**ALVARO J. GONZALEZ G.**  
**President**

enclosures: as announced  
copy to: SCG Board  
SCG files



## NOMINATION FOR ISRM LEOPOLD MÜLLER AWARD 2011

### DR. NICHOLAS R. BARTON

The Colombian Geotechnical Society (Sociedad Colombiana de Geotecnia–SCG) is proud to nominate Dr. Nicholas R. Barton, worldwide known rock engineer, familiarly known as Dr. Nick Barton, for the prestigious ISRM Leopold Müller Award in 2011.

Dr. Barton is one of the most remarkable and productive engineers in the world. Researcher and consultant, author and professor, he has been of enormous talent to conduct the engineering science in the field of rock mechanics to apply this theoretical knowledge to the practical field of rock engineering.

One of Dr. Barton's initial main contributions refer to the study of rock discontinuities: In 1972, while doing research at NGI, Barton developed his comprehensive peak shear strength criterion for rock joints, already present in his PhD thesis, involving variable roughness JRC (estimated by profiling, or tilt test) and variable wall-strength JCS (estimated by Schmidt hammer). In 1976 the basic friction angle  $\Phi_b$  for flat un-weathered surfaces was replaced by  $\Phi_r$ , following direct shear tests performed by Vishnu Choubey, on 130 partly weathered rock joint samples representing numerous rock types. In this period Barton invented the gravity-loaded tilt test for pre-characterizing JRC, useful when joints such as those recovered in drill core are not too rough. Thousands of such tests have been performed, allowing concentrating on lesser numbers of direct shear tests. In this period Barton also linked the shear strength of intact rock to that of fractured rock, up to the brittle-ductile transition, and beyond, publishing the results in 1976. Mobilization and degradation of joint roughness JRC with displacement was proposed by Barton in 1978, and following application of peak-JRC, JCS and  $\Phi_r$  in some remarkable scale-effect shear testing by Stavros Bandis, the non-linear and block-size-dependent Barton-Bandis model linking deformation, dilation and aperture: both physical and conducting, was developed in 1982, while in Terra Tek. In 1985 'BB' was installed as a sub-routine in Cundall's remarkable UDEC code, in the form UDEC-BB.

Dr Barton developed the well known Q-system of rock mass characterization in 1973, which has had worldwide application for site characterization and support design for subterranean work in rocks, mainly tunnels and large caverns, with more recent links to seismic velocities and deformation moduli and input for numerical modelling at dam sites. He has pioneered the use of NMT, the Norwegian Method of Tunnelling for use with the Q-system, in countries outside Norway, as an economic single shell alternative to other traditional methods of tunnel design and support such as NATM.

Dr. Barton subsequently linked the Q-value to tunnel and cavern deformation, and to rock mass deformation modulus: each rather crudely in 1980, but more realistically some 15 years later, when seismic velocity was researched. The parameter  $Q_c$  (Q normalised by



compressive strengths different from 100 MPa) correlated well with seismic velocity and deformation modulus. This linkage was reported in 1995 and also in Barton's 730-page text book: *Rock Quality, Seismic Velocity, Attenuation and Anisotropy*, published in 2006.

These practical linkages were applied during consulting at several dam sites, including two very high dams in Iran: one will eventually reach a height of 315 m. Another interest in dams beyond foundation and abutment deformability and stability was Barton's earlier constitutive model for the shear strength and deformability of rockfill, published in 1981, involving parameters  $R$  and  $S$  and  $\Phi_b$ , unless weathered, in which case  $\Phi_r$ . Parameters  $R$  and  $S$  are equivalent to JRC and JCS for rock joints. With these four parameters, and knowledge of the porosity of the rockfill, Barton was able to estimate rockfill-rock-foundation interface shear strength, and the possible need for roughening of the foundation. The terms 'R-controlled' and 'JRC-controlled' behaviour were coined.

Dr. Barton has also developed the  $Q_{TBM}$  method in 1999, for predicting TBM single-shield and double-shield performance in jointed and faulted rock, and for estimating TBM tunnel rock reinforcement and support needs. As a result he has worked on several TBM projects, mostly for contractors, occasionally for owners or consultants, in Italy, Kashmere, Hong Kong, Brazil, Germany/South Africa, Australia, Peru, Canada, Chile and Norway. He also has worked in the past on characterization of joints and modelling for petroleum reservoir compaction and subsidence studies, and performed hydro-fracturing stress measurements for oil companies, in petroleum reservoirs and cap rocks in several countries, including the Norwegian North Sea.

Dr. Nick Barton has 40 years of experience working with a variety of rock engineering projects, mostly in civil engineering in more than 30 countries, including deep tunnels in Norway, Italy and Kashmir, and a deep 1.6 km mine shaft instrumentation in the USA. He has specialised in international nuclear waste and tunnelling and cavern projects in recent years, working mainly for contractors and design consortia. He has performed nuclear waste disposal related rock mass characterization, and repository studies in USA (several locations, including Yucca Mountain), UK (caverns) and Sweden (Stripa, Forsmark, Simpevarp, Äspö). He has provided rock mass characterization advice in mines in South Africa, Canada, Australia, Brazil and Chile. Projects have most frequently involved tunnels and rock caverns, and sometimes dam abutments, for the hydropower and transportation industry, including the 62m span Gjøvik cavern in Norway, and the planned 315m high Bakhtiari dam in Iran.

Dr. Barton has 7 international Awards which includes the 8<sup>th</sup> Laurits Bjerrum Memorial Lecture in Oslo, 1985 and the 4<sup>th</sup> Manuel Rocha Memorial Lecture in Lisbon, 1987. He has also the honorary degree as Doctor *Honoris Causa* by University of Cordoba, Argentina, in 2004. He was Coordinator of ISRM Working Group (Suggested methods for quantitative descriptions of discontinuities in rock masses [1974-1980]) and is member of the Advisory Board of the Journal of Rock Mechanics (1982-present).



His academic activities include the posts of Adjunct Professor, Dept. of Mining, University of Utah (1983-1984); Adjunct Professor, Dept. of Rock Mechanics, University of Luleå (1985-1989); Visiting Professor, São Paulo University (1997-2001). He has also taught numerous rock engineering Q-based short courses in some ten countries

He is the author and co-author of 256 papers published in technical journals and conference proceedings. He has written two books: "TBM tunnelling in Jointed and Faulted Rock", 2000 (Balkema Ed.) and "Rock Quality, Seismic Velocity, Attenuation and Anisotropy", 2006 (Taylor and Francis Ed.).

He was also member of ISRM Committee on Rock Joints (1988-1992); ISRM Scale Effects in Rock Mechanics (1988-1992); ISRM Committee on Failure Mechanisms in Underground Openings (1988-1990).

Dr. Barton has a solid base working internationally for tasks such as expert missions, project panels, expert witness to tribunals and courts, and troubleshooting of projects.

Presented by

**SOCIEDAD COLOMBIANA DE GEOTECNIA**

**ALVARO J. GONZALEZ G.**  
President

# Curriculum Vitae

**Name:** BARTON, Nicholas R.

**Date of birth:** 10th August 1944

**Nationality:** British

**Education:** University of London, King's College,  
1966 - BSc (Eng) Honours, in Civil Engineering.  
Imperial College, London,  
1971 – PhD in Rock Mechanics, on Rock Slope Stability

**Languages:** English (mother tongue), Norwegian (fluent)

**Countries worked in as rock engineering consultant:** Norway, Germany, Kenya, Peru, South Africa, Surinam, Papua New Guinea, Greece, USA, Canada, Netherlands, Sweden, Taiwan, Israel, Hong Kong, China, Turkey, England, Japan, South Korea, Malaysia, Italy, Kashmir, Brazil, Spain, Wales, Australia, Chile, Dominican Republic, Panama, Iran, Colombia

## Key qualifications:

Developed the Q-system of rock mass characterization in 1973, which now has world-wide application for site characterization and support design for tunnels and large caverns, with more recent links to seismic velocities and deformation moduli and input for numerical modelling at dam sites. Pioneered and developed practical tools in the 1970's and 1980's, now widely used for describing rock masses as jointed media (*i.e.*, JRC, JCS,  $\phi_r$  and the Barton-Bandis constitutive model), and supervised use of such methods in numerical modelling (*i.e.* UDEC-BB). Has pioneered the use of NMT, the Norwegian Method of Tunnelling for use with the Q-system, in countries outside Norway, as an economic single shell alternative to other traditional methods of tunnel design and support such as NATM.

Has 40 years of experience working with a variety of rock engineering projects, mostly in civil engineering in more than 30 countries, including deep tunnels in Norway, Italy and Kashmir, and a deep 1.6 km mine shaft instrumentation in the USA. Has specialised in international nuclear waste and tunnelling and cavern projects in recent years, working mainly for contractors and design consortia. Performed nuclear waste disposal related rock mass characterization, and repository studies in USA (several locations, including Yucca Mountain), UK (caverns) and Sweden (Stripa, Forsmark, Simpevarp, Äspö). Has provided rock mass characterization advice in mines in South Africa, Canada, Australia, Brazil and Chile.

Projects have most frequently involved tunnels and rock caverns, and sometimes dam abutments, for the hydropower and transportation industry, including the 62 m span Gjøvik cavern in Norway, and the planned 315 m high Bakhtiary dam in Iran.

Developed the  $Q_{TBM}$  method in 1999, for predicting TBM single-shield and double-shield performance in jointed and faulted rock, and for estimating TBM tunnel rock reinforcement and support needs. As a result has worked on several TBM projects, mostly for contractors, occasionally for owners or consultants, in Italy, Kashmere, Hong Kong, Brazil, Germany/South Africa, Australia, Peru, Canada, Chile and Norway. Has worked in the past on characterization of joints and modelling for petroleum reservoir compaction and subsidence studies, and performed hydro-fracturing stress measurements for oil companies, in petroleum reservoirs and cap rocks in several countries, including the Norwegian North Sea.

Has a solid base working internationally for tasks such as expert missions, project panels, expert witness to tribunals and courts, and trouble-shooting on projects. Has taught numerous rock engineering Q-based short courses in some ten countries, and has had visiting / adjunct professor lecturing assignments in USA, Sweden and Brazil.

**Positions:**

- 2001- Present Principal, Nick Barton & Associates (Norway and Brazil)
- 2000- Present Senior international consultant, NGI, Oslo
- 1990-1999 Technical Adviser, Rock Engineering and Reservoir Mechanics Division, NGI, Oslo
- 1984-1989 Division Director, Dam, Rock and Avalanche Division, NGI, Oslo.
- 1983-1984 Manager of Geomechanics, Terra Tek Inc., Salt Lake City, Utah.
- 1980-1983 Senior Staff Consultant, Terra Tek Inc., Salt Lake City, Utah.
- 1971-1980 Senior Engineer, Dam and Rock Group, NGI, Oslo.

**Professional Societies:**

- Norwegian Civil Engineering Society NIF/Tekna
- Norwegian Geotechnical Society NGF
- Norwegian Rock Mechanics Group NBG
- Norwegian Rock Blasting Society NFF
- International Society for Rock Mechanics ISRM
- Brazilian Geotechnical Society ABMS

**Professional Posts:**

- Coordinator of ISRM Working Party "Suggested methods for the quantitative description of discontinuities in rock masses". 1974 to 1980.
- Member of AEG Rock Mechanics Committee 1981-1984.
- Advisory Board, Journal of Rock Mechanics 1982-present.
- Adjunct Professor, Dept. of Mining, University of Utah, 1983-1984.
- Adjunct Professor, Dept. of Rock Mechanics, University of Luleå, 1985-1989.
- Visiting Professor, Sao Paulo University, 1997- 2001.
- ISRM Committee on Rock Joints, 1988-1992.
- ISRM Committee on Scale Effects in Rock Mechanics, 1988-1992.

- ISRM Committee on Failure Mechanisms in Underground Openings, 1988-1990.

**Awards:**

- US National Committee for Rock Mechanics 1975 Research Award for paper: "Engineering Classification of Rock Masses for the Design of Tunnel Support"
- Geological Society of America 1978 Burwell Award for paper: "The Shear Strength of Rock and Rock Joints"
- 8th Laurits Bjerrum Memorial Lecture, Oslo, 1985.
- 4th Manuel Rocha Memorial Lecture, Lisbon, 1987.
- Biographical Citations: since 1993, Who's Who in the World; since 1994, Who's Who in Science and Engineering, Marquis biannual Editions.
- 12<sup>th</sup> Prague Geotechnical Lecture 2004
- Doctor Honoris Causa (honorary doctor) degree, University of Cordoba, Argentina, 2004.

**International Symposia, Conferences and Congresses on Rock Mechanics:**

Invited lectures (I), Keynote lectures (K), Panelist reports (P), Moderator reports (M), and General reports (G) (see publication list at the end):

Capri 1977 (P), Berkeley 1982 (K), Lisbon 1983 (P), Montreal ISRM 1987 (M), Loen 1990 (K), Istanbul 1993 (K), (P), Tokyo ISRM Congress 1995 (K), Sydney 1996 (K), Taipei 1996 (K), Shimla 1998 (K), Cancun North American NARMS 1998 (G), Santos 1998 (K), Paris ISRM Congress 1999 (G), Singapore 2000 (K), São Paulo 2002 (K), Three Gorges China 2004 (K), Cordoba-Argentina 2004 (K), Kyoto ARMS 2004 (K), Cartagena, Colombia, 2006 (I), Vancouver, 2007 (I), Oslo, Norway, 2007 (I), Bogota, Colombia, 2008 (I), Oslo, Norway, 2008 (I), San Jose, Costa Rica, 2009 (I), Cavtat, Croatia, 2009 (K), Hong Kong, 2009 (K)

**Publications** (see publication list at the end):

- Author/co-author of 256 papers in technical journals and conference proceedings.
- Author of two books: on 'TBM tunnelling in Jointed and Faulted Rock', 2000 (Balkema) and on 'Rock Quality, Seismic Velocity, Attenuation and Anisotropy', 2006 (Taylor & Francis)

**Engineering practice:**

**2009 –**

Extensive rock-exposure statistical Q-logging and use of core and seismic data to enable Q<sub>t</sub> prognosis modelling for open-gripper TBM, and for double-shield TBM with push-off-liner where needed, for twin high-speed rail tunnels of 7.5 and 9.5 km length, from Oslo to Ski for Norwegian Rail Authority JBV. Independent project reviewer for MTR's Hong Kong metro projects WIL, XRL and SIL East, involving tunnels, station caverns, and a large multi-project ventilation shaft, with application of Q-histogram logging and evaluation of numerical logging. Consultant to Indian Northern Railways concerning some possible alternative NMT-style

tunnelling strategies for 60 tunnels, review of steep rock slopes, and two major bridge foundations along the new Kashmir J&K rail link currently under construction in mountainous terrain. Expert Panel member for 2.5 km deep TBM tunnelling at the Jinping II 4,500 hydroelectric project in China, Ertan Power Company. Consultant to Camargo Correa CCC consortium in Medellin, Colombia, concerning spillway-hillside slope stability problems, and tunnel leakage and faulting problems at the PORCE III hydroelectric project. Expert Panel member for 230 m high double-arch concrete dam abutments, Karun IV Dam, Iran, for Mahab Ghodss Consulting Co. Teheran, concerning abutment and wedge stability shear strength questions. Consultant to Quieroz Galvão concerning litigation questions, for the 18 km headrace tunnel of the La Higuera hydroelectric project in Chile.

**2008–**

Consultant to consortium CVA, for development of the first major report submitted to the authorities, explaining the likely causes of the unique metro station collapse in São Paulo in January, 2007. Consultant to the Iranian Water Power and Resources Development Company (IWPC) concerning possible economic re-design of the pressure tunnel linings at the 1400 MW Gotvand Dam Project in S. Iran. Consultant to mining consultants SRK and Chilean Mining authority Codelco, for aspects of design, cost and construction risk for a 20 km long mineral conveyor tunnel, and 30 km of tailings transfer tunnels, some by TBM, for the Nuevo Andina mine expansion in the Andes. International Expert Panel to Atkins-Arup JV for Hong Kong's Mass Rapid Transport West Island Line railway tunnels extension plan. Consultant to BJVC joint venture consultants for evaluation of dam foundation alternatives through rock mass characterization and coupled process  $Q-V_p-E_{mass}-K$  evaluation, at the planned 315 m double-curvature concrete arch dam, at the Bakhtiary site in SW Iran. Consultant/Advisory Board for Brazilian contractor Camargo Correa concerning foundation shear strength at the Serra do Facao gravity concrete *and* rockfill dam in central Brazil.

**2007–**

Consultant group reporting to consortium CVA concerning the Pinheiros metro station accident, Brazil. Expert witness in Stockholm court, for Skanska concerning rock conditions and support needs at Botnia rail tunnels, Sweden. Rock engineering prognoses, core logging and modelling using  $Q_{TBM}$  for Los Bronces mine access tunnel, for SRK/Anglo American, Chile. Motorway rock slope stability studies using  $Q_{SLOPE}$  for Planservi/Odebrecht in Panama. Hydropower access road slope stability solutions in Dominican Republic for Planservi/Odebrecht. Feasibility study for deep and shallow pumped hydro projects for the Danish Geological Institute GEUS, in Denmark. Rock quality, support, seismic integration, for E18 road tunnels, Skanska, Finland.

**2006 –**

Advisor to Greater Vancouver Water District for rock quality questions and Technical Hearing at the Seymour-Capilano water treatment TBM access shaft. Technical expert to Munich Re and IRB Brazil insurance groups concerning the Campos Novos CFRD cracking and diversion tunnel gate breaches in Brazil, adviser to the Brazilian contractors Queiroz Galvaio concerning tunnelling of the 18 km headrace tunnel for the La Higuera hydro-electric project in Chile, consultant to CVA consortium for shallow metro tunnelling and station construction on Line 4, Sao Paulo. Completion of rock quality and seismic attributes book. Rock engineering courses in Australia (twice), Italy, Malaysia, Hong Kong.



**2005 –**

Expert witness reporting concerning tunnel collapse in weathered granites, Singapore. Logging of 1,400m of core from five inclined boreholes, with statistical rock quality and pre-injection analysis for the planned Lysaker-Sandvika double-track rail tunnel, for Jernbaneverket, Oslo. Advisor to Greater Vancouver Water District concerning rock quality questions concerning a deep access shaft and the twin Seymour-Capilano TBM water tunnels. Principal activity in 2005 was work on a 700 page textbook 'Rock Quality, Seismic Velocity, Attenuation and Anisotropy'.

**2004 –**

Continued work as expert witness to contractors, for a TBM litigation in Brisbane, Australia for EROC-Obayashi, and for a hydropower tunnel rapid drawdown case in The Phillipines for Transfield, and for a motorway tunnel with pre-grouting design errors in Stockholm for contractor NCC. Site characterization reporting for SKB's high level nuclear waste candidate sites at Forsmark and at Simpevarp, in eastern Sweden. Consultant to consortium of contractors concerning TBM construction of Lot 2 of Line 4 of São Paulo metro. Consultant to Jernbaneverket for input data needed for groundwater draw-down modelling at Jong-Asker rail tunnels. Consultant to Harza Brasileira concerning tailrace tunnel failures in Ponte de Pedra HEP, Brazil. Consultant to Odebrecht for planned 1 to 2 km deep trans-Andean TBM water transfer Olmos Tunnel of 14km length in Peru, with Q and Q<sub>tbm</sub> prognoses and sub-contracted modelling of stress, deformation and fracturing problems.

**2003 –**

Q-system based core characterization and joint description for four 1000m deep boreholes at SKB's Forsmark and Simpevarp candidate HLW nuclear waste repository sites in Sweden, and related surface outcrop characterization at both sites. Rock mass characterization and property estimation for the two sites, and for the APSE pillar experiment at SKB's Äspö underground hard rock laboratory. Expert witness for a hydropower tunnel in the Phillipines, and for a TBM project in Australia. Independent expert to NCC concerning pre-injection problems in Sweden. Consultant to Camargo Correa contractors, for analysis and tunnelling solutions for the rock burst problems in the Monte Claro HEP 12x16m headrace tunnel in basalts, in southern Brazil. Consultant to Latina and LAMSA concerning rock mass characterization and seismic cross-hole measurements for assessing local supplementary support needs in a motorway tunnel in Rio de Janeiro.

**2002 –**

Consultant to Camargo Correa i Brazil on stability aspects of the final 270m long jointed rock coffer dam at UHE Tucuruí for the opening of the Stage II 4500 MW development. Consultant with Maffei Engenharia for the Salvador Metro Consortium concerning rock bolt and shotcrete support needs for the metro tunnel and station with exceptionally low rock cover. International panellist reviews of SKB nuclear waste-related rock mechanics project in Äspö, Sweden. NFR and Norwegian Road Authority research report on theoretical and empirical understanding of high pressure pre-injection and the possibilities for improved rock mass properties and reduced tunnel support. Consultant to NCC concerning pre-injection difficulties in the Södra Länken ring road tunnels, Stockholm. Consultant to Jernbaneverket, Sandvika, Norway, for rock mass and core characterization and interpretation of pre-grouting and tunnel support needs at the twin track Jong-Asker rail tunnels. Consultant to Bechtel-SAIC (BSC) on rock joint description and modelling, and Think Tank member for the Yucca Mountain HLW repository, USA.

**2001 –**

Consultant to Kajima Corp., Japan for compressed air surge chamber design for pumped hydro regulation. Consultant to Bau Eng. Consultants in S.Korea for NMT tunnel design. Consultant to Hochtief, Germany for **Qtbm** analysis and modelling of a Lesotho TBM tunnel in basalts. Consultant to Bechtel-SAIC (BSC) for characterization at the Yucca Mountain HLW repository project in Nevada. Expert Panel Member and consultant to SKB, Sweden for the rock mechanics and characterization of HLW nuclear waste sites. Consultant to NCC for Södra Länken Stockholm ring-road pre-grouting claims. Consultant to the Queiroz Galvao-Constran Consortium for the final design of NMT support for Rodoanel Ring Road Tunnel T3, Sao Paulo, Brazil. Consultant to Triunfo Contractors in Curitiba, Brazil concerning **Qtbm** prognoses for a planned TBM tunnel at the Salto Natal HEP.

**2000 –**

Consultant to Morrisson Knudsen/TRW on characterization and design of the Yucca Mountain high level nuclear waste repository project in jointed tuff, Nevada, USA. Consultant to Swedish Nuclear Fuel Co. (SKB) on hydro-thermo-mechanical effects in nuclear waste repositories in jointed rock. Consultant to Skanska International for the F1 SSDS Strategic Sewage TBM tunnel in Hong Kong, using the **Qtbm** prognosis model. Consultant to Dong IL Consultants for NMT designs in S.Korea. Consultant to CBPO-Odebrecht on the Itá UHE spillway No. 2 erosion problem, caused by exceptional near-surface stresses in basalt. Consultant to Camargo Correa on the Machadinho HEP in Brazil, concerning support needs in the diversion tunnels. Consultant to Maffei Eng./Harza for rock mass and core characterization, and for NMT (B+Sfr) final designs for rail tunnels and a station cavern, for the Salvador Metro in Brazil. Consultant to the Immigrantes Consortium in Brazil, concerning tunnel reinforcement for the New Immigrantes escarpment Tunnels.

**1997 - 1999**

Consultant to Selmer A/S on Söndra Länken tunnels, Stockholm. Independent expert to Thyssen Tunnelling on Avon Mwldan Tunnel, Cardigan, Wales, concerning a poor rock conditions claim. Consultant to Axon Ltd. on Patras, Pireaus and Platamonas Tunnels in Greece. Consultant to DM Iberia and Ginprosa on high speed railtunnel, Madrid-Zaragoza line, Spain. Consultant to Hyundai on EDZ test tunnel and KAERI nuclear waste research tunnel in S. Korea. Consultant to Terra Geotechnics on Sunway Lagoon Tunnel in Kuala Lumpur. Consultant to NOCON on TBM head race tunnel, Pont Ventoux Hydro Project, Italy. Consultant to Statkraft on TBM head race tunnel, Dul Hasti Hydro Project, Kashmir. Consultant to State Road Authority, Finnmark, Norway on sub-sea Nordkapp Tunnel. Consultant to CBPO-Odebrecht on the Itá UHE, Brazil concerning stress fracturing problems in diversion and pressure tunnels caused by high stress in some basalt flows. Consultant to Engecorps for the planned 16 km long Cuncas Tunnel in the San Francisco water transfer project in Brazil, using the **Qtbm** prognosis model.

**1990-1996**

Project Manager of NGI's geotechnical consultancy to UK Nirex Ltd. Member of Nirex's Site Characterisation and Advisory Group and Geotechnical Study Group. The NGI project includes geotechnical characterisation of some 10 km of drill cores, numerical analysis and rock engineering design of the caverns, and associated excavations and planning of the *in situ* testing for the Rock Characterisation Facility at Sellafield.

Consultant to Fuji Research Institute Corporation for Japan Highways Tomei II motorway tunnel, using NMT design methods and numerical verifications. Consultant to Dragages in Hong Kong concerning Route 3 motorway tunnels to new airport. Consultant to Amy-Metom in Haifa, concerning Mount Carmel tunnel project. Reference group member for Kraftbyggarna in Sweden, concerning 9m diameter TBM tunnels for high speed railway through Hallandsås, South Sweden. Consultant to GeoEngineering in Jersey, concerning the ET- Eurotunnel claim involving predictable rock mass conditions in the jointed chalk marl, especially km 20-24 of the Channel Tunnel, on the British side of the English Channel. Rock cavern consultant to Geotechnical Control Office, Hong Kong. Project manager for anchor tunnel foundation studies, Tsing Ma suspension bridge, Hong Kong. Reference group member for SSDS Strategic Sewage tunnels in Hong Kong for Mott Connell. Consultant to Carmel Tunnels project management, Ayalon Highways Co. Ltd in Israel. Project Manager for the 62 m span Gjøvik Olympic cavern rock mechanics design studies performed by NGI for consultants Fortifikasjon A/S in Norway.

**1989-1990**

Project Manager for NGI's lab. and *in situ* joint characterisation and numerical modelling, Stripa Phase III, Site Characterisation and Validation Project 1986-1991, where he was Principal Investigator in rock mechanics. Consultant to Shell, The Hague, on cryogenic storage in caverns in jointed rock. Field mapping and support recommendation for 49 km of tunnels for Solakli Hydropower project, Turkey for Norendel/Berdal-Strømme. World Bank Expert Panel, Rock Engineering, for Xiaolangdi multipurpose hydro project, Yellow River, China.

**1988-1989**

Project Manger for studies on gas storage in lined caverns, Statoil. Characterisation of rock mass for numerical modelling of gas storage caverns, Grängesberg, Sweden, for State Power Board (Vattenfall). UN Development Project Consultant, Indian hydropower project, Lakhwar, and lecture tour. Consultant to Noranda Mining Co., Canada, on rock mass characterisation and numerical modelling. Kajima Foundation, promotion of science lecture tour, Japan. Consultant to Atomic Energy of Canada Ltd on nuclear waste isolation laboratory and field tests and numerical modelling of shaft response.

**1987-1988**

Consultant to Sinotech, on Mingtan pumped hydropower station stability for static and seismic loading, Taiwan. Expert panel, Statkraft, on deformation in underground powerhouses. Expert panel, Fjellinjen motorway tunnels, Statens Vegvesen. Manager for lab. and *in situ* joint characterisation and numerical modelling project in Phase III of Stripa International Nuclear Waste Isolation Project, 1986-1991. Consultant to Israeli Department of Defence on cavern stability. Rock mass characterisation for numerical modelling of Oscar Mining Project, LKAB, Sweden.

**1986-1987**

Evaluation of tunnel support designs for Service Tunnel, Channel Tunnel Group Ltd, London. Manager for 3 year joint oil industry research programme on borehole stability during drilling and production. Minihydrofrac stress measurement supervision and interpretation for Phillips Petroleum Co. in Albuskjell field, North Sea.

***1984-1986***

Evaluation of stability of circular tunnels in soft seabed sediments for access to North Sea oil reservoirs (Troll in Fjell project). Evaluation of support requirements and instrumentation needs for the Lubuge hydropower excavations in S.W. China, for Advisory Group of Norway. Project manager for North Sea Ekofisk chalk reservoir compaction and subsidence, lab. and numerical studies for Norwegian Petroleum Directorate. Manager for joint characterisation and discrete element numerical modelling for major road tunnel project, Fjellinjen, Oslo.

***1980-1984***

Project manager for the following projects (while in USA):

Rock mass characterisation of basalts for nuclear waste repository tunnel support design, Rockwell Hanford Operations. Joint characterisation and coupled flow-deformation modelling of Nevada Test Site (NTS) welded tuff, Sandia National Laboratories, Albuquerque, New Mexico. Modelling the shear resistance of soft rock to rapid sub-sea dredging, for Delft Hydraulics Laboratories, Holland. Instrumentation and analysis of a 1.6 km deep section of the Silver Shaft, Hecla Mining Co., Idaho, for the US Bureau of Mines. Large scale static and dynamic shear testing of rock joints, using 1m<sup>3</sup> samples, Defense Nuclear Agency. Large scale shear tests on rockfill material and large scale geotechnical tests of backfilled shafts, Dept. of Energy.

Large scale deformation tests in pressure tunnel at Rocky Mountain Pumped Hydro project, Georgia. Hydrothermomechanical joint modelling and description of nuclear waste repository design, CANMET, Ottawa. Site Characterisation and data analysis for the Office of Nuclear Waste Isolation (ONWI) 8m<sup>3</sup> heated block test of jointed gneiss, Colorado. Consultant to Dames and Moore concerning large scale values of joint shear stiffness for the Nine Mile Point nuclear power plant foundations. Hydraulic fracturing stress measurements at Georgia Power Co. Rocky Mountain Pumped Hydro. Constitutive modelling of joint shear-dilation-permeability coupling for ONWI. Hydraulic fracturing stress measurements at NAM's 3000m deep Coevorden gas well, Holland. Consultant to Department of Defense, Israel, on rock support for underground storage cavern in chalk.

***1971-1980***

Norwegian Geotechnical Institute, Oslo, Senior Engineer, Dam and Rock Group.

***1979-1980***

Consulted for Norconsult in Papua, New Guinea concerning support recommendations for the Rouna 4 hydroelectric project. Consulting projects for the Norwegian State Power Board included tunnel and power station support recommendations, and arch dam stability calculations for the Alta, Breheimen and Ulla-Førre hydroelectric projects. Developed methods for estimating the full-scale shear strength of rockfill, and of the foundation interfaces beneath rockfill dams. Performed a stability evaluation of two near-surface limestone mines, and supervised the installation of displacement monitoring equipment.

***1977-1978***

Consultant for Norconsult in Surinam concerning foundation permeability and grout curtain requirements for two dams of the Kabalebo hydropower project. Planned the drilling program for the Rouna 4 project in Papua New Guinea. Consulted for Boliden Metall AB concerning contact zone joint parameters in the Nåæsliden cut and fill mine in northern Sweden. Consulted for the

Swedish State Power Board concerning joint characterisation by means of novel large scale shear tests at the Forsmark nuclear power station. Developed recommendations for combating swelling rock problems at nuclear power plant excavations in New York State, for Dames and Moore. Classification of rock mass conditions for finalising permanent support for tunnels of the Ulla-Førre, Eidfjord and Kjela hydropower projects, Norwegian State Power Board. Conducted physical model studies of very large span near-surface underground openings for the Swedish State Power Board, investigating the effect of changes in horizontal stress and joint orientations on deformation.

***1975-1976***

Conducted anchor pull-out tests in jointed rock for assessing the stability of a 60m diameter ammonia tank, and recommended stabilising measures of a large chlorine cavern, for Norsk Hydro's Rafnes refinery. Consultant to the Swedish consortium Skånska Cement, concerning permanent support for the Gitaru hydropower project in Kenya, and for the Majes Irrigation tunnels, Peru. Consultant to Golder Associates in South Africa concerning support recommendations for the Drackensburg Pumped Storage project. Evaluation of slope stability problems experienced along a major new coastal road in Greece, for Geomechaniki. Feasibility study for underground siting of a nuclear power plant, Norwegian State Power Board. Conducted a detailed study of the shear strength of rock joints and associated scale effects. Developed theory linking the shear strength of rock and rock joints up to the brittle-ductile transition.

***1973-1974***

Developed a rock mass classification method (Q-system) for estimating the permanent support requirements of tunnels and large underground openings. Researched the problems of clay-filled discontinuities and their effect on rock slope stability. Evaluated rock anchor requirements for a major road cutting, Oslo Kommune. Evaluated the slope stability and designed remedial measures for a critical slope above a Norwegian west coast community. Evaluated the reservoir side-slope stability at the Svartevann Dam, West Norway.

***1971-1972***

Conducted a parallel plate model study for evaluating leakage rates of compressed air through saturated, jointed rock masses from compressed air surge chambers, Norwegian State Power Board. Evaluated water pumping tests and radioactive tracer tests at a potential site for an underground nuclear power plant, Norwegian State Power Board.

December, 2009.

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