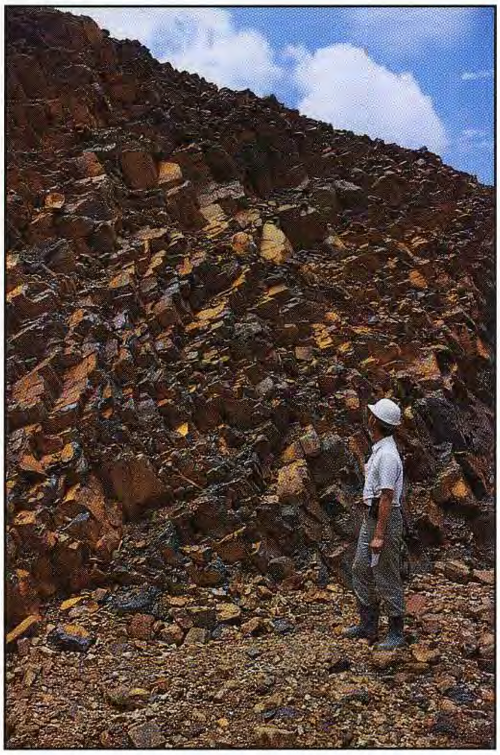
Société Internationale de Mécanique des Roches

INTERNATIONAL SOCIETY FOR ROCK MECHANICS

Internationale Gesellschaft für Felsmechanik

NEWS JOURNAL



Surface exposure of heavily bedded sandstone.

Top heading of cable bolted excavation in heavily bedded sandstone.

Estimating the strength of the bedded sandstone shown here was a critical part of the design process for the 25 m span powerhouse constructed on the site. See page 4 — *Strength of Rock & Rock Masses*.

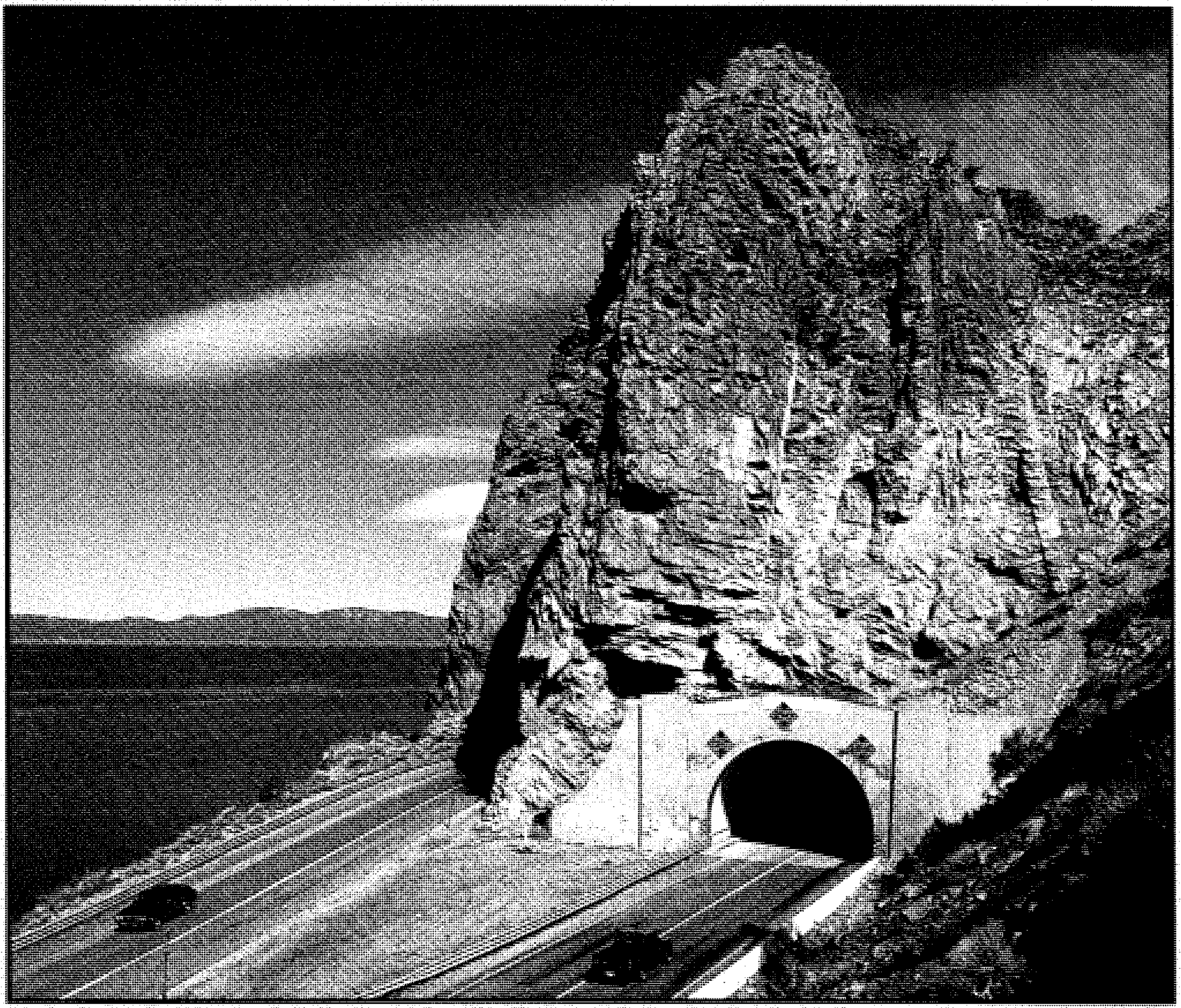
IN EVERY ISSUE

ARTICLES

Volume 2 Number 2

35th U.S. Symposium on Rock Mechanics

Lake Tahoe
June 4-7, 1995



Cave Rock, Lake Tahoe/ *Photo by Jim Grant*

A symposium to present a broad overview of the state of the art in rock mechanics, featuring papers on present, ongoing or recently completed research, as well as examples of current practice.

For symposium information, call:
Jaak Daemen, Chairman
Professor of Mining Engineering
University of Nevada, Reno
(702) 784-4309

For registration information, call:
Division of Continuing Education
University of Nevada, Reno
(702) 784-4046

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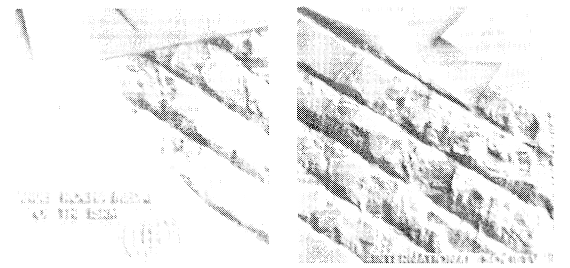
Rocha Medal for 1996



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 the name, nationality, place and date of birth of the nominee; also position, address, telephone and 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 copy the thesis for purposes of review and selection only.

Nominations for the 1996 Rocha Medal must be received by 1994 December 31.

Supplementary details of the selection procedure, conferring of the award, etc., are provided in ISRM By-Law No. 7, found on pages 29–30 of the ISRM Directory for 1992–93. 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.

From the President

Charles Fairhurst

Annual Symposium in Santiago

The Annual ISRM International Symposium is always an important event for the Society. It is one of only four opportunities for the President and Board to meet with the ISRM Council, and with invited guests representing other international organizations with professional interests related to those of the Society. It is a time to assess the global well-being of ISRM and to make decisions affecting the future of the Society.

The 1994 International Symposium, the Fourth South-American Congress on Rock Mechanics, was hosted by the Sociedad Chilena de Geotechnica (SOCHIGE), the Chilean National Group of ISRM, in conjunction with the World Mining Exposition, EXPOMIN, in Santiago, May 10-14. Arrangements and general hospitality for the Board and Council Meetings (which took place May 8-9) and indeed, throughout the Symposium, were exceptional, with grateful thanks due to Prof. M. Van Sint Jan, Symposium Chairman, Mr. Luis Valenzuela and Mr. Guillermo Noguerra, the current President of SOCHIGE.

The close relationship with other international societies was well demonstrated at the Council meeting. The International Society for Soil Mechanics and Foundation Engineering (ISSMFE) was represented by Mr. Luis Valenzuela, currently ISSMFE Vice-President for South America. In 1992 it was Mr. Valenzuela, then President of SOCHIGE, who made the application for Chile to be the host of the 1994 International Symposium. The representative for the International Commission on Large Dams (ICOLD) was Mr. Guillermo Noguerra.

The meeting provided an exceptional opportunity to become familiar with the considerable breadth of challenging rock mechanics and rock engineering problems in the various countries of Latin America. The Nazca tectonic plate and subduction zone run parallel to the coast of Chile, so that earthquakes and related tectonic stresses are an important concern in the country. Mines in the Andes have experienced rockbursts, and rockburst control was a special workshop topic at the Symposium. It was clear that advances are being made in the fight against the rockburst hazard—improved seismic instrumentation systems, geophysical interpretation, geo-tomography and numerical modeling of the mechanics of rockbursts and unstable deformation of rock masses.

— Continued on page 44

☆ Call for Nominations ☆

ISRM Board 1995–1999 Offices of ISRM President and Regional Vice-Presidents

The ISRM Board for the term 1995–1999 will be elected at the Council meeting to be held 26 September 1995 in Tokyo, Japan, in conjunction with the 8th ISRM Congress.

National Groups are invited to nominate their candidates for office. In order to meet the stipulations of the ISRM Statutes and By-Law No. 2, nominations must reach the ISRM Secretariat before 26 March 1995.

Please do your best to help the Council by nominating at least one candidate for each office before the March 26 deadline.

Full details of the procedures for the nomination and election of ISRM officers are given in By-Law No. 2. (See ISRM Directory 1992–93, pages 17–19.)

Strength of Rock and Rock Masses

by Evert Hoek

One of the major problems in designing underground openings is that of estimating the strength and deformation properties of the in-situ rock mass. In the case of jointed rock masses, an evaluation of these properties presents formidable theoretical and experimental problems. However, since this question is of fundamental importance in almost all major designs involving excavations in rock, it is essential that some attempt be made to estimate these strength and deformation properties and that these estimates should be as realistic and reliable as possible.

Definition of the Problem

Table 1 illustrates the range of problems to be considered. Understanding the behaviour of jointed rock masses requires a study of the intact rock material and of the individual discontinuity surfaces which go together to make up the system. Depending upon the number, orientation and nature of the discontinuities, the intact rock pieces will translate, rotate or crush in response to stresses imposed upon the rock mass. Since a large number of possible combinations of block shapes and sizes exist, it is obviously necessary to find any behavioural trends which are common to all of these combinations. The establishment of such common trends is the most important objective in this paper.

Before embarking upon a study of the individual components and of the system as a whole, it is necessary to set down some basic definitions.

- *Intact rock* refers to the unfractured blocks which occur between structural discontinuities in a typical rock mass. These pieces may range from a few millimeters to several metres in size and their behaviour is generally elastic and isotropic. For most hard igneous and metamorphic rocks failure can be classified as brittle, which implies a sudden reduction in strength when a limiting stress level is exceeded. Weak sedimentary rocks may fail in a more ductile manner, in which there is little or no strength reduction when a limiting stress level is reached. Viscoelastic or time-dependent behaviour is not usually considered to be significant unless one is dealing with evaporites such as salt or potash. The mechanical properties of these viscoelastic materials are not dealt with in this paper.
- *Joints* are a particular type of geological discontinuity, but the term tends to be used generically in rock mechanics and usually covers all types of structural weakness. The shear strength of such structural weakness planes is dealt with in publications by Barton and his co-workers (1973, 1976, 1977, 1982, 1990).
- *Strength*, in the context of this discussion, refers to the maximum stress level which can be carried by a specimen. The presentation of rock strength data and its incorporation into a failure criterion depends upon the preference of the individual and upon the end use for which the criterion is intended. In dealing with gravity-driven wedge failure problems, where limit equilibrium methods of analyses are used, the most useful failure criterion is one which expresses the shear strength in terms of the effective normal stress, acting across a particular weakness plane or shear zone. On the other hand, when analysing the stability of underground excavations in medium to high stress regimes, the response of the rock to the principal stresses acting upon each element is of paramount interest. Consequently, for the underground excavation engineer, a plot of triaxial test data, in terms of the major principal stress at failure versus minimum principal stress, is the most useful form of failure criterion.

Strength of Intact Rock

A vast amount of information on the strength of intact rock has been published during the past fifty years and it would be inappropriate to attempt to review it all here. Interested readers are referred to the excellent review presented by Jaeger (1971).

Hoek and Brown (1980a, 1980b) and Hoek (1983) reviewed the published information on intact rock strength and proposed an empirical failure criterion for rock. In developing their empirical failure criterion, Hoek and Brown attempted to satisfy the following conditions:

a. The failure criterion should give good agreement with rock strength values determined from laboratory triaxial tests on core samples of intact rock. These samples are typically 50 mm in diameter and should be oriented perpendicular to any discontinuity surfaces in the rock.

b. The failure criterion should be expressed by mathematically simple equations based, to the maximum extent possible, upon dimensionless parameters.

c. The failure criterion should offer the possibility of extension to deal with the failure of jointed rock masses.

Consulting Engineer, 412-2150 West Broadway, Vancouver, B.C. Canada, V6K 4L9, Fax: 1-604-222-3732.

Extract from a book entitled *Support of Underground Excavations in Hard Rock* by E. Hoek, P.K. Kaiser and W.F. Bawden. See page 15.

Based on their experimental and theoretical experience with the fracture mechanics of rock, Hoek and Brown (1980a, 1980b) experimented with a number of distorted parabolic curves to find one which gave good coincidence with the original Griffith theory (Griffith, 1921 & 1924). Griffith was concerned with brittle failure in glass and he expressed his relationship in terms of tensile stresses. Hoek and Brown sought a relationship which fitted the observed failure conditions for brittle rocks subjected to compressive stress conditions.

Note that the process used by Hoek and Brown in deriving their empirical failure criterion was one of pure trial and error. Apart from the conceptual starting point provided by the Griffith theory, there is no fundamental relationship between the empirical constants included in the criterion and any physical characteristics of the rock. The justification for choosing this particular criterion over the numerous alternatives lies in the adequacy of its predictions of observed rock fracture behaviour, and the convenience of its application to a range of typical engineering problems.

The Hoek-Brown failure criterion for intact rock may be expressed in the following form:

$$\sigma_1' = \sigma_3' + \sigma_c \left(m_i \frac{\sigma_3'}{\sigma_c} + 1 \right)^{1/2} \quad (1)$$

where:

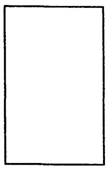
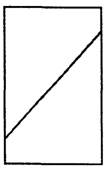
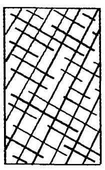
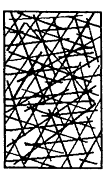
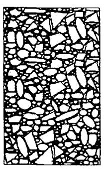
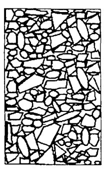
σ_1' is the major principal effective stress at failure

σ_3' is the minor principal effective stress at failure

σ_c is the uniaxial compressive strength of the intact rock

m_i is a material constant for the intact rock.

Table 1. Summary of rock mass characteristics, testing methods and theoretical considerations.

	Description	Strength characteristics	Strength testing	Theoretical considerations
	Intact rock	Brittle, elastic and generally isotropic behaviour	Triaxial testing of core specimens relatively simple and inexpensive and results are usually reliable	Behaviour of elastic isotropic rock is adequately understood for most practical applications
	Intact rock with a single inclined discontinuity	Highly anisotropic, depending on shear strength and inclination of discontinuity	Triaxial tests difficult and expensive. Direct shear tests preferred. Careful interpretation of results required	Behaviour of discontinuities adequately understood for most practical applications
	Massive rock with a few sets of discontinuities	Anisotropic, depending on number, orientation and shear strength of discontinuities	Laboratory testing very difficult because of sample disturbance and equipment size limitations	Behaviour of complex block interaction in sparsely jointed rock masses poorly understood
	Heavily jointed rock masses	Reasonably isotropic, highly dilatant at low stress levels with particle breakage at high stress levels	Triaxial testing of representative samples extremely difficult because of sample disturbance	Behaviour of interlocking angular pieces poorly understood
	Compacted rockfill or weakly cemented conglomerates	Reasonably isotropic, less dilatant and lower strength than in situ rock due to destruction of fabric	Triaxial testing simple but expensive due to large equipment required to accommodate samples	Behaviour reasonably well understood from soil mechanics studies on granular materials
	Loose waste rock or gravel	Poor compaction and grading allow particle movement resulting in mobility and low strength	Triaxial or direct shear testing simple but expensive due to large size of equipment	Behaviour of loosely compacted waste rock and gravel adequately understood for most applications

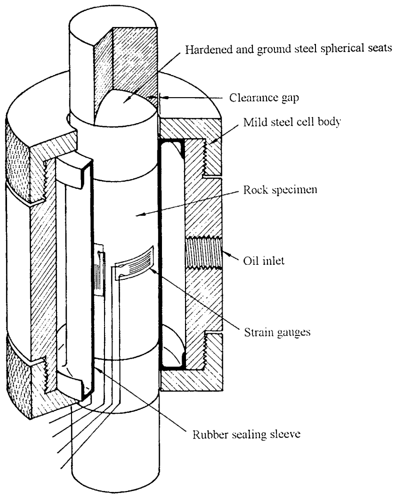


Figure 1. Simple triaxial cell used for testing rock cores in field laboratories. The rubber sealing sleeve is designed to retain the oil so that the cell does not need to be drained between tests. Cells are available to accommodate a variety of standard core sizes.

Whenever possible, the value of σ_c should be determined by laboratory testing on cores of approximately 50 mm diameter and 100 mm in length. In some cases, where the individual pieces of intact rock are too small to permit samples of this size to be tested, smaller diameter cores may be tested. Hoek and Brown (1980a) suggested that the equivalent uniaxial compressive strength of a 50 mm diameter core specimen can be estimated from:

$$\sigma_c = \frac{\sigma_{cd}}{\left(\frac{50}{d}\right)^{0.18}} \qquad (2)$$

where σ_{cd} is the uniaxial strength measured on a sample of d mm in diameter.

The most reliable values of both the uniaxial compressive strength σ_c and the material constant m_i are obtained from the results of triaxial tests. For typical igneous and metamorphic rocks and for strong sedimentary rocks, such as sandstones, these laboratory tests are routine and there are many laboratories around the world which have excellent facilities for triaxial testing. In weak sedimentary rocks, such as shales and siltstones, preparation of specimens for triaxial testing can be very difficult because of the tendency of these materials to slake and delaminate, when subjected to changes in moisture content. A solution, which has been used on several major engineering projects, is to carry out the triaxial tests in the field, usually in exploration adits or access tunnels, using a triaxial cell described by Franklin and Hoek (1970) and illustrated in Figure 1. This cell has a rubber sealing sleeve, which is designed to contain the pressurising fluid (usually oil), so that there is no need for drainage between tests. A diamond saw is used to trim the ends of the core sample and a capping compound is applied to produce parallel ends. A 50 ton capacity load frame provides a sufficiently high axial load for most of these weak rocks. Confining pressure is provided by a simple hand-operated pump.

The specimen should be cored normal to significant discontinuities, such as bedding planes, and the tests should be carried out on specimens which have a moisture content as close to in-situ conditions as possible. Although it is possible to obtain porous platens so that pore fluid pressures can be controlled, this control is not practical in field testing situations and a reasonable compromise is to keep loading rates low in order to avoid generation of dynamic pore pressures.

The triaxial test results can be processed using a program called ROCKDATA[2] developed by Shah (1992). This program is based upon the simplex reflection statistical technique which has been found to produce the most reliable interpretation of triaxial test data.

When time or budget constraints do not allow a triaxial testing program to be carried out, the values of the constants σ_c and m_i can be estimated from Tables 2 and 3. Table 3 is based upon analyses of published triaxial test results on intact rock (Hoek, 1983; Doruk, 1991 and Hoek et al., 1992).

A detailed discussion on the characteristics and limitations of the Hoek-Brown failure criterion, including the transition from brittle to ductile failure and the mechanics of anisotropic failure, has been given by Hoek (1983). These considerations are very important in the application of the failure criterion to the behaviour of intact rock. They may need to be considered when dealing with foliated rocks such as gneisses, which can exhibit strongly anisotropic behaviour, or with sedimentary rocks such as limestones and marbles, which may become ductile at low stress levels. However, in the context of this paper, these detailed considerations are of secondary importance and will not be discussed further.

The Strength of Jointed Rock Masses

The original Hoek-Brown criterion was published in 1980 and, based upon experience in using the criterion on a number of projects, an updated version was published in 1988 (Hoek and Brown, 1988) and a modified criterion was published in 1992 (Hoek et al. 1992).

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[2]Available from The Rock Engineering Group, University of Toronto, 12 Selwood Avenue, Toronto, Ontario, Canada M4E IB2, Fax: 1 (416) 698-0908, Tlp: 1 (416) 978-4611.

Table 2. Field estimates of uniaxial compressive strength.

Grade*	Term	Uniaxial Comp. Strength (MPa)	Point Load Index (MPa)	Field estimate of strength	Examples**
R6	Extremely Strong	> 250	>10	Rock material only chipped under repeated hammer blows, rings when struck	Fresh basalt, chert, diabase, gneiss, granite, quartzite
R5	Very strong	100 - 250	4 - 10	Requires many blows of a geological hammer to break intact rock specimens	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, limestone, marble, rhyolite, tuff
R4	Strong	50 - 100	2 - 4	Hand held specimens broken by a single blow of geological hammer	Limestone, marble, phyllite, sandstone, schist, shale
R3	Medium strong	25 - 50	1 - 2	Firm blow with geological pick indents rock to 5 mm, knife just scrapes surface	Claystone, coal, concrete, schist, shale, siltstone
R2	Weak	5 - 25	***	Knife cuts material but too hard to shape into triaxial specimens	Chalk, rocksalt, potash
R1	Very weak	1 - 5	***	Material crumbles under firm blows of geological pick, can be shaped with knife	Highly weathered or altered rock
R0	Extremely weak	0.25 - 1	***	Indented by thumbnail	Clay gouge

* Grade according to ISRM (1981).

** All rock types exhibit a broad range of uniaxial compressive strengths which reflect the heterogeneity in composition and anisotropy in structure. Strong rocks are characterised by well interlocked crystal fabric and few voids.

*** Rocks with a uniaxial compressive strength below 25 M [illegible] ely to yield highly ambiguous results under point load testing.

The most general form of the Hoek Brown criterion, which incorporates both the original and the modified form, is given by the equation:

$$\sigma_1' = \sigma_3' + \sigma_c \left(m_b \frac{\sigma_3'}{\sigma_c} + s \right)^a \qquad (3)$$

where:

- ❖ m_b is the value of the constant m for the rock mass
- ❖ s and a are constants which depend upon the characteristics of the rock mass
- ❖ σ_c is the uniaxial compressive strength of the intact rock pieces and
- ❖ σ_1 and σ_3 are the axial and confining effective principal stresses respectively.

The original criterion has been found to work well for most rocks of good to reasonable quality in which the rock mass strength is controlled by tightly interlocking angular rock pieces. The failure of such rock masses can be defined by setting $a = 0.5$ in equation 3, giving:

$$\sigma_1' = \sigma_3' + \sigma_c \left(m_b \frac{\sigma_3'}{\sigma_c} + s \right)^{0.5} \qquad (4)$$

For poor quality rock masses in which the tight interlocking has been partially destroyed by shearing or weathering, the rock mass has no tensile strength or "cohesion" and specimens will fall apart without confinement. For such rock masses the modified criterion is more appropriate and this is obtained by putting $s = 0$ in equation 3 which gives:

$$\sigma_1' = \sigma_3' + \sigma_c \left(m_b \frac{\sigma_3'}{\sigma_c} \right)^a \qquad (5)$$

It is practically impossible to carry out triaxial or shear tests on rock masses at a scale which is appropriate for surface or underground excavations in mining or civil engineering. Numerous attempts have been made to overcome this problem by testing small scale models, made up from assemblages of blocks or elements of rock or of carefully designed model materials. While these model studies have provided a great deal of valuable information, they generally suffer from limitations arising from the assumptions and simplifications, which have to be made in order to permit construction of the models. Consequently,

Table 3. Values of the constant m_i for intact rock, by rock group. Note that values in parenthesis are estimates.

Rock type	Class	Group	Texture: Course	Texture: Medium	Texture: Fine	Texture: Very fine
SEDIMENTARY	Clastic		Conglomerate (22)	Sandstone 19	Siltstone 9	Claystone 4
				← Greywacke (18) →		
	Non-Clastic	Organic		← Chalk 7 →		
				← Coal (8-21) →		
		Carbonate	Breccia (20)	Sparitic Limestone (10)	Micritic Limestone 8	
		Chemical		Gypstone 16	Anhydrire 13	
METAMORPHIC	Non Foliated		Marble 9	Hornfels (19)	Quartzite 24	
	Slightly foliated		Migmatite (30)	Amphibolite 31	Mylonites (6)	
	Foliated*		Gneiss 33	Schists (10)	Phyllites (10)	Slate 9
IGNEOUS	Light		Granite 33		Rhyolite (16)	Obsidian (19)
			Granodiorite (30)		Dacite (17)	
			Diorite (28)		Andesite 19	
	Dark		Gabbro 27	Dolerite (19)	Basalt (17)	
			Norite 22			
	Extrusive pyroclastic type		Agglomerate (20)	Breccia (18)	Tuff (15)	

*These values are for intact rock specimens tested normal to bedding or foliation. The value of m_i will be significantly different if failure occurs along a weakness plane (Hoek, 1983).

our ability to predict the strength of jointed rock masses on the basis of direct tests or of model studies is severely limited.

Equations 4 and 5 are of no practical value unless the values of the material constants m_b, s and a can be estimated in some way. Hoek and Brown (1988) suggested that these constants could be estimated from the 1976 version of Bieniawski's Rock Mass Rating (*RMR*), assuming completely dry conditions and a very favourable joint orientation. While this process is acceptable for rock masses with *RMR* values of more than about 25, it does not work for very poor rock masses since the minimum value which *RMR* can assume is 18. In order to overcome this limitation, a new index called the Geological Strength Index (*GSI*) is introduced. The value of *GSI* ranges from about 10, for extremely poor rock masses, to 100 for intact rock. The relationships between *GSI* and the rock mass classifications of Bienawski and Barton, Lein and Lunde will be discussed later.

The relationships between m_b / m_i, s and a and the *GSI* are as follows:

$$\frac{m_b}{m_i} = \exp\left(\frac{GSI - 100}{28}\right) \tag{6}$$

For *GSI* > 25 (Undisturbed rock masses):

$$s = \exp\left(\frac{GSI - 100}{9}\right) \tag{7}$$

$$a = 0.5 \tag{8}$$

For *GSI* < 25 (Undisturbed rock masses):

$$s = 0.5 \tag{9}$$

$$a = 0.65 - \frac{GSI}{200} \tag{10}$$

Since many of the numerical models and limit equilibrium analyses used in rock mechanics are

ESTIMATE OF HOEK-BROWN AND MOHR-COULOMB PARAMETERS

Input : GSI = 62 sigci = 100 mi = 24

Output:		sig3	sig1	ds1ds3	sign	tau	signtau	signsq
mb/mi =	0.26	0.10	14.48	22.47	0.71	2.91	2.07	0.51
mb =	6.18	0.20	16.55	19.89	0.98	3.49	3.41	0.96
s =	0.015	0.39	20.09	16.68	1.50	4.55	6.85	2.26
a =	0.5	0.78	25.87	13.31	2.53	6.39	16.20	6.42
E =	19953	1.56	34.91	10.26	4.52	9.48	42.90	20.46
phi =	48	3.13	48.70	7.78	8.32	14.48	120.44	69.18
coh =	3.4	6.25	69.56	5.88	15.45	22.31	344.80	238.78
sigcm =	18.0	12.5	101.20	4.48	28.68	34.26	982.51	822.60
				Sums =	62.70	97.88	1519.17	1161.16

Cell formulae:

```
mb/mi = EXP((GSI-100)/28)
   mb = mi*EXP((GSI-100)/28)
    s = IF(GSI>25 THEN EXP((GSI-100)/9) ELSE 0)
    a = IF(GSI>25 THEN 0.5 ELSE (0.65-GSI/200))
    E = 1000*10^((GSI-10)/40)
 sig3 = sigci/2^n where n starts at 10 and decreases by 1 for each subsequent cell
 sig1 = sig3+sigci*(((mb*sig3)/sigci) + s)^a
ds1ds3 = IF(GSI>25 THEN 1+(mb*sigci)/(2*(sig1-sig3)) ELSE 1+(a*mb^a)*(sig3/sigci)^(a-1))
 sign = sig3+(sig1-sig3)/(1+ds1ds3)
  tau = (sign-sig3)*SQRT(ds1ds3)
signtau = sign*tau              signsq = sign^2
  phi = (ATAN((sum(signtau)-(sum(sign)*sum(tau))/8)/(sum(signsq)-((sum(sign))^2)/8)))*180/PI()
  coh = (sum(tau)/8) - (sum(sign)/8)*TAN(phi*PI()/180)
sigcm = (2*coh*COS(phi*PI()/180))/(1-SIN(phi*PI()/180))
```

Figure 2. Spreadsheet for the calculation of Hoek-Brown and Mohr-Coulomb parameters.

expressed in terms of the Mohr-Coulomb failure criterion, it is necessary to estimate an equivalent set of cohesion and friction parameters for given Hoek-Brown values. This can be done using a solution published by Balmer (1952) in which the normal and shear stresses are expressed in terms of the corresponding principal stresses as follows:

$$\sigma_n = \sigma_3 + \frac{\sigma_1 - \sigma_3}{\partial\sigma_1 / \partial\sigma_3 + 1} \quad (11)$$

$$\tau = (\sigma_n - \sigma_3)\sqrt{\partial\sigma_1 / \partial\sigma_3} \quad (12)$$

For the *GSI* > 25, when $a = 0.5$:

$$\frac{\partial\sigma_1}{\partial\sigma_3} = 1 + \frac{m_b\,\sigma_c}{2\,(\sigma_1 - \sigma_3)} \quad (13)$$

For the *GSI* < 25, when $s = 0$:

$$\frac{\partial\sigma_1}{\partial\sigma_3} = 1 + a m_b^a \left(\frac{\sigma_3}{\sigma_c}\right)^{a-1} \quad (14)$$

Once a set of (σ_n, τ) values have been calculated from equations 11 and 12, average cohesion *c* and friction angle ϕ values can be calculated by linear regression analysis, in which the best fitting straight line is calculated for the range of (σ_n, τ) pairs.

The uniaxial compressive strength of a rock mass defined by a cohesive strength *c* and a friction angle ϕ is given by:

$$\sigma_{cm} = \frac{2c.\cos\phi}{1 - \sin\phi} \quad (15)$$

A simple spreadsheet for carrying out the full range of calculations presented above is given in Figure 2.

Use of Rock Mass Classifications for Estimating Geological Strength Index (GSI)

In searching for a solution to the problem of estimating the strength of jointed rock masses and to provide a basis for the design of underground excavations in rock, Hoek and Brown (1980a, 1980b) felt that some attempt had to be made to link the constants *m* and *s* of their criterion to measurements or observations which could be carried out by any competent geologist in the field. Recognising that the characteristics of the

	PARAMETER		RANGE OF VALUES						
1	Strength of intact rock material	Point-load strength index	>8 MPa	4 - 8 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial compressive strength	>200 MPa	100 - 200 MPa	50 - 100 MPa	25 - 50 MPa	10-25 MPa	3-10 MPa	1-3 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of joints		> 3 m	1 - 3 m	0.3 - 1 m	50 - 300 mm	< 50 mm		
	Rating		30	25	20	10	5		
4	Condition of joints		Very rough surfaces Not continuous No separation Hard joint wall contact	Slightly rough surfaces Separation < 1 mm Hard joint wall contact	Slightly rough surfaces Separation < 1 mm Soft joint wall contact	Slickensided surfaces OR Gouge < 5 mm thick OR Joints open 1-5 mm Continuous joints	Soft gouge >5 mm thick OR Joints open > 5 mm Continuous joints		
	Rating		25	20	12	6	0		

Table 4. Part of Bieniawski's 1976 table defining the Geomechanics Classification or Rock Mass Rating (RMR) for jointed rock masses.

rock mass which control its strength and deformation behaviour are similar to the characteristics which had been adopted by Bieniawski (1973) and by Barton et al. (1974) for their rock mass classifications, Hoek and Brown proposed that these classifications could be used for estimating the material constants *m* and *s*.

In preparing this paper it became obvious that there was a need to consolidate these various versions of the criterion into a single simplified and generalised criterion to cover all of the rock types normally encountered in underground engineering.

The rock mass classifications by Bieniawski (1974) and Barton et al. (1974) were developed for the estimation of tunnel support. They were adopted by Hoek and Brown (1980a) for estimating *m* and *s* values because they were already available and well established in 1980, and because there appeared to be no justification for proposing yet another classification system. However, there is a potential problem in using these existing rock mass classification systems as a basis for estimating the strength of a rock mass.

Consider a tunnel in a highly jointed rock mass subjected to an in-situ stress field such that failure can occur in the rock surrounding the tunnel. When using the Tunnelling Quality Index Q proposed by Barton et al. (1974) for estimating the support required for the tunnel, the in-situ stress field is allowed for by means of a Stress Reduction Factor. This factor can have a significant influence upon the level of support recommended on the basis of the calculated value of Q. An alternative approach to support design is to estimate the strength of the rock mass by means of the Hoek-Brown failure criterion. This strength is then applied to the results of an analysis of the stress distribution around the tunnel, in order to estimate the extent of zones of overstressed rock requiring support. If the Barton et al. classification has been used to estimate the values of *m* and *s*, and if the Stress Reduction Factor has been used in calculating the value of Q, it is clear that the influence of the in-situ stress level will be accounted for twice in the analysis.

Similar considerations apply to the Joint Water Reduction Factor in Barton et al.'s classification and to the Ground Water term and the Rating Adjustment for Joint Orientations in Bieniawski's *RMR* classification. In all cases there is a potential for double counting, if these factors are not treated with care when using these classifications as a basis for estimating the strength of rock masses.

In order to minimise potential problems of the type described above, the following guidelines are offered for the selection of parameters when using rock mass classifications as a basis for estimating *m* and *s* values for the Hoek-Brown failure criterion.

Bieniawski's 1976 RMR classification

Bieniawski has made several changes to the ratings used in his classification (Bieniawski, 1973, 1974, 1976, 1979, 1989) and the significance of these changes is best appreciated by considering the following typical example:

A slightly weathered granite has an average Point-load strength index value of 7 MPa, an average *RQD* value of 70%, and slightly rough joints with a separation of < 1 mm, are spaced at 300 mm. The *RMR* values for this rock mass, calculated using tables published by Bieniawski in the years indicated, are as follows:

Item	Value	1973	1974	1976	1979	1980
Point load index	7 MPa	5	5	12	12	12
RQD	70%	14	14	13	13	13
Spacing of discontinuities	300 mm	20	20	20	10	10
Condition of discontinuities	Described	12	10	20	20	25
Groundwater	Dry	10	10	10	15	15
Joint orientation adjustment	Very favourable	15	15	0	0	0
	RMR	76	74	75	70	75

The differences in these values demonstrate that it is essential that the correct ratings be used. The 1976 paper by Bieniawski is the basic reference for this work. For the convenience of the reader, the relevant parts of Bieniawski's 1976 Geomechanics Classification table are reproduced in Table 4.

In using Bieniawski's 1976 Rock Mass Rating to estimate the value of GSI, Table 4 should be used to calculate the ratings for the first four terms. The rock mass should be assumed to be completely dry and a rating of 10 assigned to the Groundwater value. Very favourable joint orientations should be assumed and the Adjustment for Joint Orientation value set to zero. The final rating, called RMR_{76}', can then be used to estimate the value of GSI:

For $RMR_{76}' > 18$

$$GSI = RMR_{76}' \qquad (16)$$

For $RMR_{76}' < 18$ Bieniawski's 1976 classification cannot be used to estimate GSI and Barton, Lein and Lunde's Q' value should be used instead.

Bieniawski's 1989 RMR classification

Bieniawski's 1989 classification can be used to estimate the value of GSI in a similar manner to that described above for the 1976 version. In this case a value of 15 is assigned to the Groundwater rating and the Adjustment for Joint Orientation is again set to zero. Note that the minimum value which can be obtained for the 1989 classification is 23 and that, in general, it gives a slightly higher value than the 1976 classification. The final rating, called RMR_{89}', can be used to estimate the value of GSI:

For $RMR_{89}' > 23$

$$GSI = RMR_{89}' - 5 \qquad (17)$$

For $RMR_{89}' < 23$ Bieniawski's 1976 classification cannot be used to estimate GSI and Barton. Lein and Lunde's Q' value should be used instead.

Modified Barton, Lien and Lunde's Q classification

In using this classification to estimate GSI, the Rock Quality Designation (RQD), joint set number (Jn), joint roughness number (Jr) and joint alteration number (Ja) should be used exactly as defined in the tables published by Barton et al. (1974).

For the joint water reduction factor (Jw) and the stress reduction factor (SRF), use a value of 1 for both of these parameters, equivalent to a dry rock mass subjected to medium stress conditions. The influence of both water pressure and stress should be included in the analysis of stresses acting on the rock mass for which failure is defined in terms of the Hoek-Brown failure criterion.

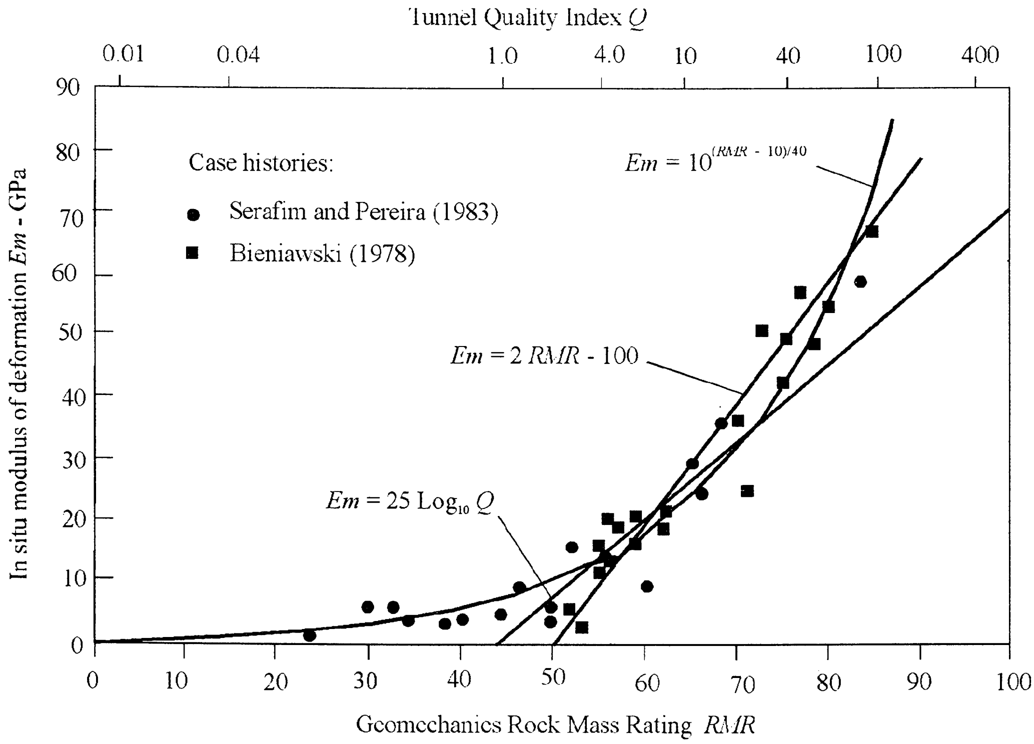


Figure 3. Prediction of in-situ deformation modulus E_m from rock mass classifications.

Table 5. Estimation of constants m_b/m_i, s, a, deformation modulus Em and the Poisson's ratio ν for the Generalised Hoek-Brown failure criterion based upon rock mass structure and discontinuity surface conditions. Note that the values given in this table are for an undisturbed rock mass.

GENERALISED HOEK-BROWN CRITERION

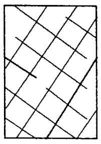
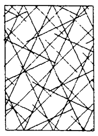
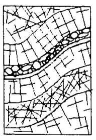
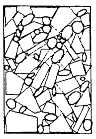
$$\sigma_1' = \sigma_3' + \sigma_c \left(m_b \frac{\sigma_3'}{\sigma_c} + s \right)^a$$

σ_1' = major principal effective stress at failure

σ_3' = minor principal effective stress at failure

σ_c = uniaxial compressive strength of *intact* pieces of rock

m_b , s and a are constants which depend on the composition, structure and surface conditions of the rock mass

STRUCTURE		SURFACE CONDITION	VERY GOOD Very rough, unweathered surfaces	GOOD Rough, slightly weathered, iron stained surfaces	FAIR Smooth, moderately weathered or altered surfaces	POOR Slickensided, highly weathered surfaces with compact coatings or fillings containing angular rock fragments	VERY POOR Slickensided, highly weathered surfaces with soft clay coatings or fillings
	BLOCKY - very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets	m_b/m_i	0.60	0.40	0.26	0.16	0.08
		s	0.190	0.062	0.015	0.003	0.0004
		a	0.5	0.5	0.5	0.5	0.5
		E_m	75,000	40,000	20,000	9,000	3,000
		ν	0.2	0.2	0.25	0.25	0.25
		GSI	85	75	62	48	34
	VERY BLOCKY - interlocked, partially disturbed rock mass with multifaceted angular blocks formed by four or more discontinuity sets	m_b/m_i	0.40	0.29	0.16	0.11	0.07
		s	0.062	0.021	0.003	0.001	0
		a	0.5	0.5	0.5	0.5	0.53
		E_m	40,000	24,000	9,000	5,000	2,500
		ν	0.2	0.25	0.25	0.25	0.3
		GSI	75	65	48	38	25
	BLOCKY/SEAMY - folded and faulted with many intersecting discontinuities forming angular blocks	m_b/m_i	0.24	0.17	0.12	0.08	0.06
		s	0.012	0.004	0.001	0	0
		a	0.5	0.5	0.5	0.5	0.55
		E_m	18,000	10,000	6,000	3,000	2,000
		ν	0.25	0.25	0.25	0.3	0.3
		GSI	60	50	40	30	20
	CRUSHED - poorly interlocked, heavily broken rock mass with a mixture of angular and rounded blocks	m_b/m_i	0.17	0.12	0.08	0.06	0.04
		s	0.004	0.001	0	0	0
		a	0.5	0.5	0.5	0.55	0.60
		E_m	10,000	6,000	3,000	2,000	1,000
		ν	0.25	0.25	0.3	0.3	0.3
		GSI	50	40	30	20	10

Note 1. The in situ deformation modulus E_m is calculated from equation 21. Units of E_m are MPa.

Hence, for substitution into equation 7, the modified Tunnelling Quality Index (Q') is calculated from:

$$Q' = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \qquad (18)$$

This value of Q' can be used to estimate the value of GSI from:

$$GSI = 9 \text{Log}_e Q' + 44 \qquad (19)$$

Note that the minimum value for Q' is 0.0208 which gives a *GSI* value of approximately 9 for a thick, clay-filled fault or shear zone.

Estimation of In-Situ Deformation Modulus

The in-situ deformation modulus of a rock mass is an important parameter in any form of numerical analysis and in the interpretation of monitored deformation around underground openings. Since this parameter is very difficult and expensive to determine in the field, several attempts have been made to develop methods for estimating its value, based upon rock mass classifications.

In the 1960's several attempts were made to use Deere's *RQD* for estimating in-situ deformation modulus, but this approach is seldom used today (Deere and Deere, 1988).

Bieniawski (1978) analysed a number of case histories and proposed the following relationship for estimating the in situ deformation modulus, E_m, from RMR:

$$E_m = 2RMR - 100 \qquad (20)$$

Based on the analyses of a number of case histories, many of which involved dam foundations for which the deformation moduli were evaluated by back analysis of measured deformations, Serafim and Pereira (1983) proposed the following relationship between E_m and *RMR:*

$$E_m = 10^{\frac{(RMR - 10)}{40}} \qquad (21)$$

More recently Barton et al. (1980), Barton et al. (1992) and Grimstad and Barton (1993) have found good agreement between measured displacements and predictions from numerical analyses using in situ deformation modulus values estimated from:

$$E_m = 25 \, Log_{10}Q \qquad (22)$$

Curves defined by equations 20, 21 and 22, together with the case history observations of Bieniawski (1978) and Serafim and Pereira (1983) are plotted in Figure 3. This figure suggests that equation 21 provides a reasonable fit for all of the observations plotted and it has the advantage of covering a wider range of RMR values than either of the other two equations.

When to Use the Hoek-Brown Failure Criterion

The rock mass conditions under which the Hoek-Brown failure criterion can be applied are summarised in Figure 4.

The Hoek-Brown failure criterion is only applicable to intact rock or to heavily jointed rock masses which can be considered homoge-

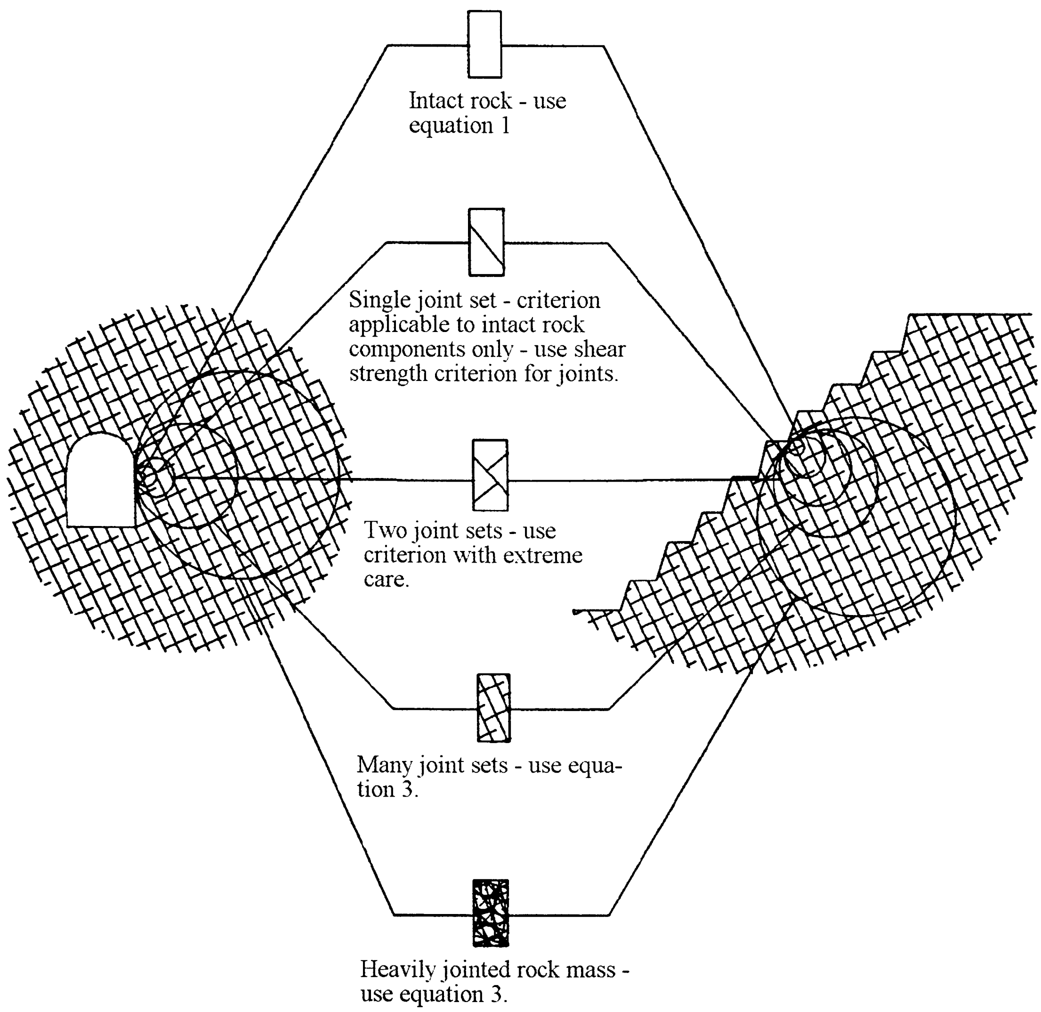


Figure 4. Rock mass conditions under which the Hoek-Brown failure criterion can be applied.

neous and isotropic. In other words the properties of these materials are the same in all directions.

The criterion should not be applied to highly schistose rocks such as slates or to rock masses in which the properties are controlled by a single set of discontinuities such as bedding planes. In cases where such rock masses are being analysed, the Hoek-Brown failure criterion applies to the intact rock components only.

The strength of the discontinuities should be analysed in terms of a shear strength criterion such as that published by Barton (1976). When two joint sets occur in a rock mass, the Hoek-Brown criterion can be used with extreme care, provided that neither of the joint sets has a dominant influence on the behaviour of the rock mass. For example, if one of the joint sets is clay coated and is obviously very much weaker than the other set, the Hoek-Brown criterion should not be used except for the intact rock components. On the other hand, when both joint sets are fresh, rough and unweathered and when their orientation is such that no local wedge failures are likely, the upper left hand box in Table 5 can be used to estimate the Hoek-Brown parameters.

For more heavily jointed rock masses in which many joints occur, the Hoek-Brown criterion can be applied and Table 5 can be used to estimate the strength parameters.

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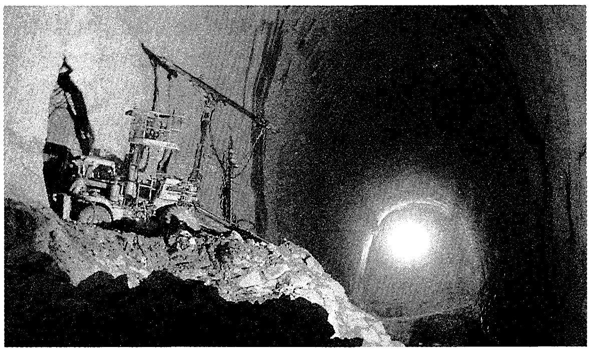

Back Analysis in Rock Engineering

by S. Sakurai

1. Introduction

Various numerical methods of analysis, such as the Finite Element Method, the Boundary Element Method, the Distinct Element Method, etc., have rapidly developed in rock mechanics during the last decade. They have been used extensively in engineering practices in designing tunnels, large caverns, slopes, dams, and so on. However, even if these sophisticated numerical methods are used, it is not an easy task to predict the mechanical behavior of the structures with sufficient accuracy. This is simply due to the fact that there are many uncertainties involved in the input data for the numerical analysis, such as geological and geomechanical characteristics of rocks, rock joint system, underground water table, permeability, initial state of stress, etc. Thus, it is not surprising that the real behaviors of the structures often differ from those predicted.

In order to fill the gap between the actual behavior and the predicted one, field measurements are performed during construction to revise the input data used in the design analysis, as well as to monitor the stability of the structures.

Revising the input data can be done in such a way that discrepancies between the real and predicted behaviors of the structures are reduced to a minimum, and if necessary, the original design and the construction method may be modified in order to achieve a rational design of the structures.

This design/construction method based on field measurements is called the "observational method." In this method, however, a question may arise concerning how to quantitatively interpret the field measurement results for assessing the original design and construction method. A technique called "back analysis" is a key to answering this question. It can bridge the gap between prediction and reality. This paper describes back analysis methods developed by the author and his co-workers.

2. Back Analysis and Ordinary Analysis

Back analysis is generally defined as a technique which can provide the controlling parameters of a system by analyzing its output behavior. In back analysis of rock engineering problems, force conditions such as external loads and/or rock pressures, and mechanical properties of rock such as modulus of elasticity, Poisson's ratio, cohesion, internal friction angle, etc., are identified from displacements, strains and pressures measured during and/or after construction.

This identifying procedure is just the reverse of an ordinary analysis, in which the force conditions and mechanical properties are the input data for determining displacements, strains and stresses. Thus, this reverse procedure is called "back analysis." It must be emphasized, however, that back analysis is not simply the reverse calculation of ordinary analysis, particularly in the sense of modeling of rock. In ordinary analysis a mechanical model is usually assumed in such a way that the rock is represented approximately by a certain model, such as an elastic, elasto-plastic, viscoplastic, discrete block model, etc. When a mechanical model is assumed, the values of the mechanical constants of the model can be determined by performing laboratory tests and/or in-situ tests. In an ordinary analysis these values are then used as input data to evaluate the resulting quantities of displacement, strain, and stress.

In back analysis, on the other hand, the usual procedure is to measure displacement, strain and/or pressure, and then to assume a mechanical model. The mechanical constants of the model can then be back analyzed from the field measurement results. Consequently, it is obvious that the back analyzed values of the mechanical constants depend entirely on what model is assumed. Thus, modeling is more important in back analysis than in ordinary analysis. It must be emphasized that in back analysis the mechanical model should not be just assumed, but should be back analyzed from the actual field measurement data. However, the final aim of back analysis, as far as engineering practice is concerned, is not merely to identify the mechanical model and its material constants, but to assess the adequacy of the original design and construction methods.

3. Back Analysis Procedures

Various back analysis procedures have been developed, ranging from those involving simple elastic models to far more complex nonlinear problems. Gioda and Sakurai (1987) have summarized these problems with particular reference to the interpretation of field measurement results.

Back analysis procedures may be roughly classified into three categories: 1. inverse approach, 2. direct approach and 3. stochastic approach. In the inverse approach, the mathematical formulation is exactly the reverse of that in ordinary analysis, although the governing equations are identical in each case. On the other hand, the direct approach is based on an iterative optimization procedure

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which corrects the trial values of unknown parameters in such a way that the discrepancy between measured and computed values are minimized. The direct approach can be applied easily to nonlinear problems without having to rely on a complex mathematical background. Nevertheless, it should be noted that the inverse approach has a great advantage in engineering practice, since in general, no iteration is required.

The inverse and direct methods are both based on a deterministic concept and provide precise values of material constants. However, it is often difficult to determine these values precisely as unique values. In overcoming this difficulty, a stochastic approach capable of taking the uncertainties of input data into account can be adopted. Among the various stochastic approaches, the Bayesian approach and the Kalman filter parameter identification method may have great potential.

4. Direct Strain Evaluation Technique (DSET)

In general, rocks contain various types of continuous planes, such as joints, bedding and faults. Thus, the deformation of rocks may be due mainly to the movement of these discontinuous planes. However, if rocks are heavily jointed, they behave in a global sense just like a continuous body. Therefore, heavily jointed rocks can be represented by a continuum model, and their deformational behavior can be analyzed by using the theory of continuum mechanics.

In order to monitor the stability of tunnels, Sakurai (1981) proposed the Direct Strain Evaluation Technique (DSET) on the basis of the theory of continuum mechanics. In the DSET, the stability of tunnels can be assessed by comparing the strain occurring in the ground surrounding the tunnels with the allowable value of the strain of rocks. The critical strain has been defined as the ratio of uniaxial compressive strength to modulus of elasticity, and it may be used as an allowable value of strain. The critical strain is generally more or less independent of environmental factors, such as confining pressure, moisture content, temperature, etc. It is also interesting to know that the critical strain of jointed rock masses is almost the same value as the one of intact rocks (Sakurai, 1983). Thus, the critical strain of large scale jointed rock masses can be predicted from laboratory tests carried out on small sized intact rocks.

If the number of displacement measurement data is sufficiently large, strain can be determined directly from the measured displacements through use of the kinematic relationship between strain and displacement. In practice, however, the number of measurement data is generally limited, and not sufficient to obtain an overall view of the strain distribution around the tunnel. In order to overcome this problem, a back analysis method has been proposed. In the method, the initial stress and material constants are first back analyzed from measured displacements. They are then used as input data for an ordinary analysis to determine the strain distribution.

In formulating the mathematical equations the following assumptions are made:

1. The mechanical characteristics of rocks are expressed by a homogeneous isotropic linear elastic model, so that the material constants are reduced to two, that is, modulus of elasticity and Poisson's ratio. In addition, for simplicity, Poisson's ratio is taken as a known value.
2. The initial stress is uniformly distributed throughout the rock being excavated.

Based on the above mentioned assumptions, the following linear relationship between measured displacements and initial stress can be derived:

$$\{u_m\} = [A]\{\sigma_0{}^*\} \quad (1)$$

where $\{u_m\}$ represents the measured displacements, and $\{\sigma_0{}^*\}$ is defined in two dimensions as: $\{\sigma_0{}^*\} = \{\sigma_{0x}/E, \sigma_{0y}/E, \tau_{0xy}/E\}$ which is called the "normalized initial stress." E denotes the modulus of elasticity. The matrix [A] is a function of Poisson's ratio and location of measurement points only. Equation (1) has the same number of equations as the number of measured displacement data, and contains three unknown values of the normalized initial stress. If the number of data is greater than three, the normalized initial stress can be determined with any optimization procedure. Adopting the least squares method, the following equation can be obtained:

$$\{\sigma_0{}^*\} = [[A]^T[A]]^{-1}[A]^T\{u_m\} \quad (2)$$

When determining the normalized initial stress, the values of initial stress and modulus of elasticity can be obtained by assuming that the vertical stress is equal to the overburden pressure. However, in order to calculate the strain distribution, it is unnecessary to separate each value for the initial stress and the modulus of elasticity, as the normalized initial stress alone is sufficient.

The above mentioned back analysis method has been extended to a three-dimensional case, in which the boundary element method is used. This method was applied successfully to back-analyze both three-dimensional initial stress and the modulus of elasticity during construction of an underground hydropower plant cavern (Sakurai and Shimizu, 1986).

5. Non-elastic Behavior of Rocks

When a non-elastic zone appears in rocks, the above mentioned back analysis must be modified. There are two approaches available for taking into account the non-elastic behavior of rocks in the framework of continuum mechanics. One approach is to consider the effects of non-elastic behavior in a constitutive equation. The second is to treat these effects as equivalent external forces, by implementing nonelastic strain.

5.1 Constitutive equation

The deformation of heavily jointed rocks may be due mainly to, (1) spalling of joints, (2) sliding along a particular slip plane, and (3) plastic flow. Thus, all three models of deformation must be taken into account by constitutive equations. A large number of investigations have already been carried out in the development of constitutive equations. However, many of them are too sophisticated to apply in engineering practices. A simple constitutive equation is preferable. In order to fulfill these requirements, anisotropic parameters have been proposed which are determined by back analysis (Sakurai, Ine and Shinji, 1988). The anisotropic parameters are also successfully used for back analysis of deformational behavior of cut slopes (Sakurai, 1990).

5.2 Equivalent external forces

The strain $\{ \varepsilon \}$ in general, consists of elastic strain $\{ \varepsilon_e \}$and a non-elastic strain $\{ \varepsilon_n \}$as follows:

$$\{ \varepsilon \}=\{ \varepsilon_e \}+\{ \varepsilon_n \} \qquad (3)$$

Applying Hooke's law, the stress is given by:

$$\{ \sigma \}=[D](\{ \varepsilon_e \} - \{ \varepsilon_n \}] \qquad (4)$$

in which [D] is an elastic stress-strain matrix for an isotropic material. Considering Equation (4) in the mathematical formulation of the finite element method, the following equation is derived:

$$[K] \{u\}=\{ P \}+\{ P_n \} \qquad (5)$$

where:

[K] : Stiffness matrix

{u} : Displacement vector at nodal points

$\{P\} = \int_{v_1}[B]^T\{\sigma_0\}dv - \int_{v_1} [N]^T\{b\}dv$

$\{P_n\} = \int_{v_2}[B]^T[D]\{\epsilon_n\}dv$

$\{ P \}$ denotes the external forces representing the excavation, where $\{ \sigma_0 \}$ is the initial stress, and $\{ b \}$ is the gravitational force. $\{ P_n \}$ denotes equivalent external forces caused by non-elastic strain. This includes spalling, sliding and/or plastic strain. V_1 represents the volume of the

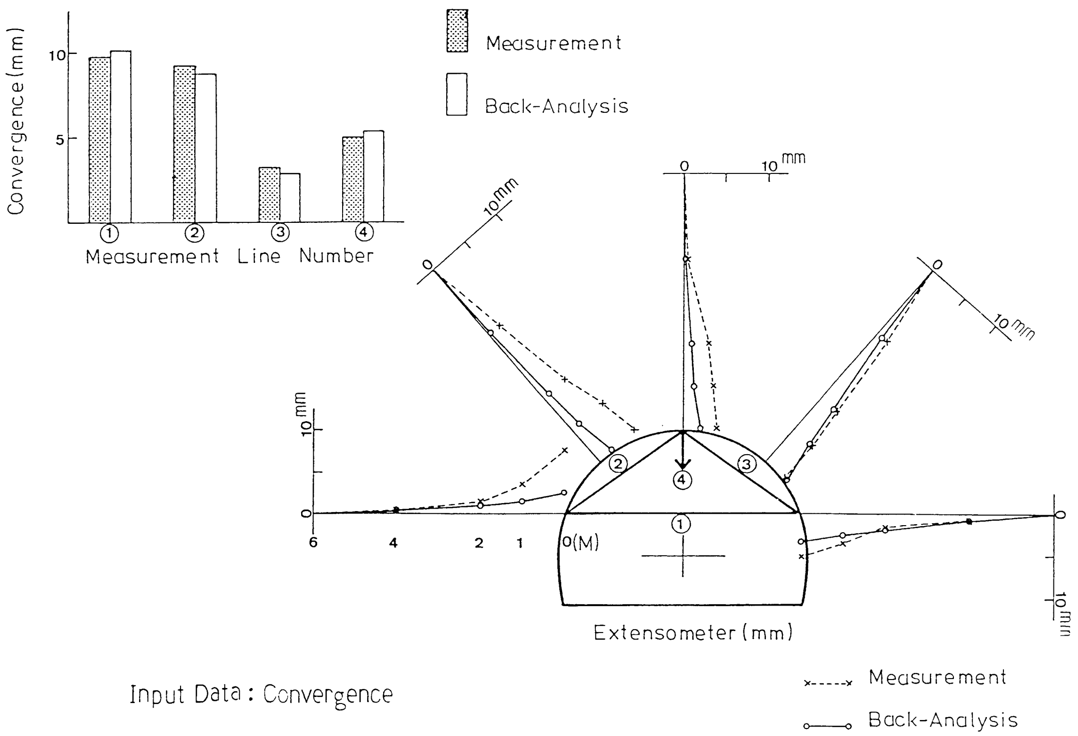


Figure 1. Comparison between measured and back-analyzed displacements around the tunnel.

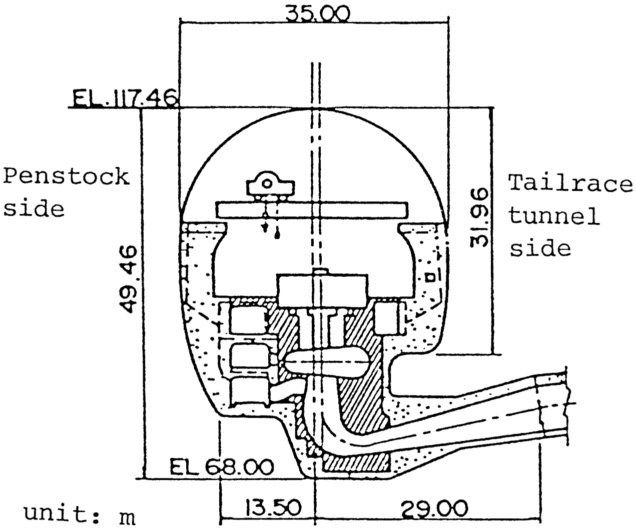


Figure 2. Cross section of the cavern.

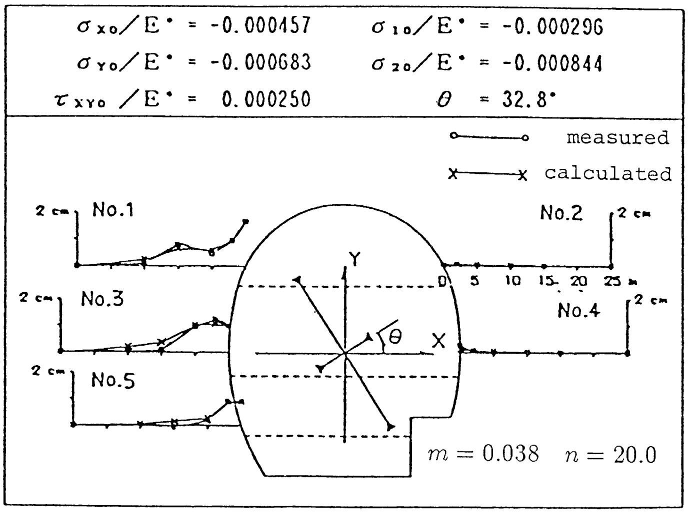


Figure 3. Results of back analysis and comparison between measured and calculated displacements.

excavation, while V_2 is the volume of the zone exhibiting non-elastic strains.

From Equation (5), a vector of measured displacements can be derived as a linear function of the unknown parameters, consisting of the normalized initial stress and nonelastic strains (Sakurai and Akutagawa, 1994). The non-elastic strains are location-dependent variables. Thus, it should be noted that if independent values of non-elastic strains are assumed in each Gaussian integration point, the number of unknown parameters becomes extremely large—often in the hundreds—which must be back analyzed uniquely from a limited number of measurements. Therefore, a stable back analysis of these unknown parameters cannot be achieved unless some form of constraint is introduced to assure uniqueness of solution; which is given, for example, by the

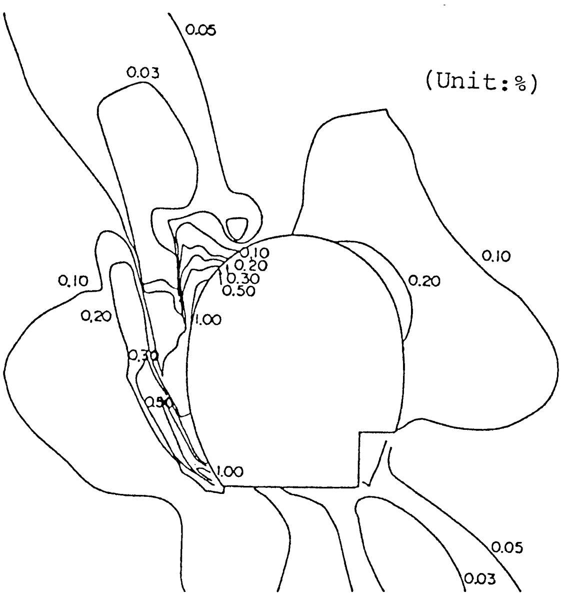


Figure 4. Maximum shear strain distribution.

minimum norm solution proposed by Gao and Mura (1992).

6. Case Studies

Case studies for demonstrating the applicability of back analysis as described in this paper have been presented elsewhere (Sakurai, 1992). A brief summary of some case studies is presented below.

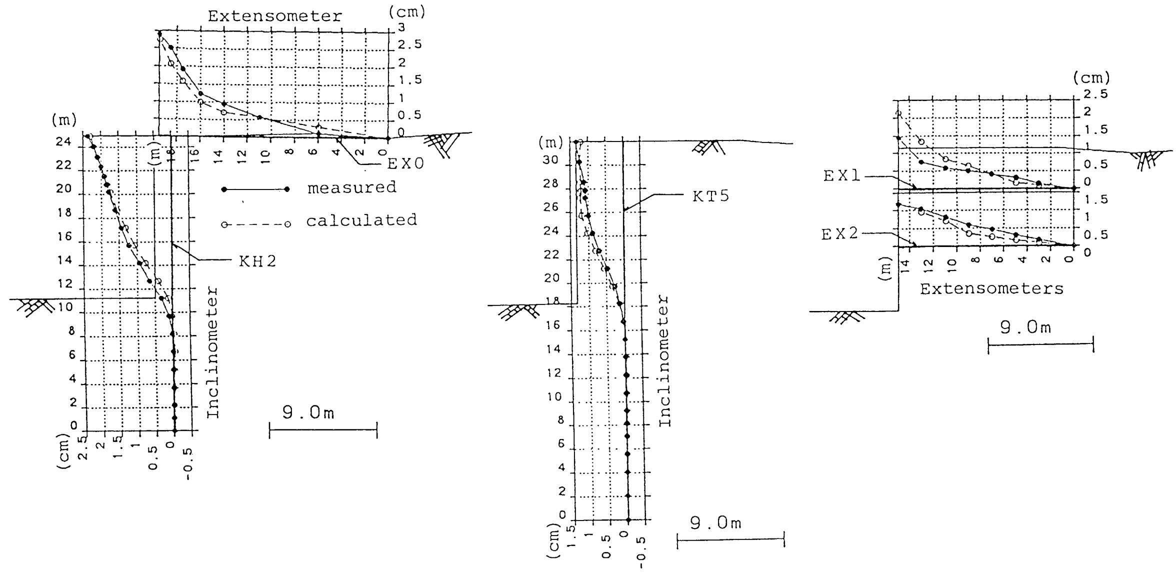
6.1 Highway tunnel

A double-lane highway tunnel was excavated in heavily weathered granite. Convergence and extensometer measurements were carried out during excavation. Assuming elastic ground, the normalized initial stress was determined by back analysis of the measured displacements, in order to calculate displacements and strains. Figure 1 shows one of the results comparing calculated displacements with the measured values.

6.2 Underground powerhouse

A large underground cavern for a hydroelectric power plant was excavated in ground consisting of tuff breccia and andesite. Field measurements were carried out during excavation to monitor the stability of the cavern, as well as to verify the adequacy of the design and construction procedure. A cross section of the cavern is shown in Figure 2. One of the locations where extensometers were installed is shown in Figure 3, together with the measured displacements and the back analysis results.

In this back analysis, anisotropic parameters were adopted to take into consideration non-elastic behavior of the cavern which developed on the side wall of the penstock. The maximum shear strain distribution obtained by the back analysis is shown in Figure 4. The stability of the cavern can then be assessed by comparing the back analysis value with a prescribed allowable value.



(a) Inclinometer KH2 and Extensometer EX0

(b) Inclinometer KT5

(c) Extensometer EX1 and EX2

Figure 5. Comparison of back analyzed displacements with measured values.

6.3 Cut slope

In this case, the rock mass was cut vertically, and supported by rock bolts with shotcrete sprayed on the free surface. The height of the cut slope reached a maximum of 25 m. The rock consisted of granite with some parts of the rock heavily weathered. The displacements were measured during cutting by use of extensometers and inclinometers. The results were back analyzed to obtain the normalized initial stress and anisotropic parameters, which were then used to calculate displacements and strains. Figure 5 shows the comparison of calculated displacements with the measured values. The maximum shear strain distribution is given in Figure 6.

Following the back analysis procedure proposed by Sakurai (1991), the cohesion and internal friction angle were determined as $c = 0.1$ MPa and $\phi = 30$ degrees, respectively. From these values, the factor of safety during cutting was computed to be $F_S = 1.7$.

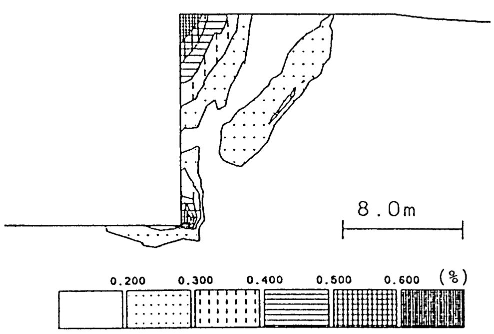


Figure 6. Maximum shear strain distribution.

7. Concluding remarks

It is well recognized that field measurements are a very powerful tool in achieving a rational design and construction procedure for rock structures such as tunnels, large caverns, cut slopes, etc. The measurement results must be interpreted properly and without delay; otherwise, they will become less meaningful. Back analysis is extremely useful in allowing a quantitative interpretation of the results.

In this paper, back analysis methods developed mainly by the author and coworkers have been presented. The methods are formulated on the basis of continuum mechanics. Non-elastic behavior of rocks can be taken into consideration when applying these methods. Since the methods do not require any iteration process, they can be applied readily in engineering practices.

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Letter to the Editor

From: Evert Hoek, Consulting Engineer

The Challenge of Input Data for Rock Engineering

There was a time, not too many years ago, when our ability to collect geotechnical data far exceeded our ability to use it for meaningful engineering analysis. This situation has been turned completely on its head and we are now faced with severe data limitations in our analyses of rock engineering problems.

The development of computer hardware and software over the past decade has been nothing short of spectacular and we are now able to carry out analyses which were unthinkable a few years ago. For an investment of a small fraction of an annual salary, the rock engineer of today can have access to portable computers and user-friendly software which was previously only available to large organizations and specialized university departments.

What about the input data for these immensely powerful tools which we now take for granted? Unfortunately the picture here is not nearly as rosy and our data collection and interpretation tools have not advanced in step with the numerical tools. Yes, we do have better drilling equipment, better geophysical techniques, better electronic control systems for our laboratory equipment, but can we do a better job of predicting the strength and deformation characteristics of a rock mass for input into a numerical model? I doubt it.

The problems of measuring the persistence of rock joints, determining the most likely failure mode for a rock mass containing a number of intersecting structural features, or of estimating the in-situ deformation modulus of a rock mass are as formidable as always. Similarly, techniques for measuring in-situ stress, while greatly improved from what they were, still give an amount of scatter which would be unacceptable in almost any other branch of engineering. These problems are all associated with the inherently heterogeneous nature of the rocks with which we have to work and, while the problems are understandable, *we have to ask what are we doing to try to improve our understanding of these problems*? The answer is very little.

As I travel around the world on my consulting assignments I see significant research funding and effort going into the development of better and faster software, the development of design techniques for tunnels, caverns and slopes of increasing size and complexity and the development of drill and blast and mechanical excavation techniques to give higher production and greater reliability. These efforts are necessary, highly commendable and have my full support. However, I see almost no research effort being devoted to the generation of the basic input data which we need for our faster and better models and our improved design techniques. These tools are rapidly reaching the point of being severely data limited.

Since testing of in-situ rock masses on a realistic scale is not practical, we have only two avenues open to us to remedy this data deficiency. The first is to develop a better understanding of how the component pieces of the rock mass interact to produce the overall behaviour which we need to understand in order to use it as input for our analyses. The second is to use back analysis of the observed performance or rock engineering structures to deduce what rock mass properties exist in these structures.

The data-hungry numerical tools which have been developed can help us in solving some of these problems. These tools are now powerful enough that we can construct realistic models of jointed rock masses and carry out parametric studies to see how they behave and why they behave the way they do. Similarly, these models enable us to carry out detailed back analyses of the sequences of excavation and of the deformations induced during the creation of slopes, dam foundations, underground hydropower caverns and tunnels. While such a back analysis may not give precise values for the parameters which we believe to be important in defining the mechanical characteristics of rock masses, the results can certainly add significantly to our body of knowledge in this field. It is not inconceivable that, if

"I see almost no research effort being devoted to the generation of the basic input data which we need for our faster and better models and our improved design techniques. These tools are rapidly reaching the point of being severely data limited."

sufficient analyses of this type are carried out, we may be able to develop a much better understanding of the type of input data which we require for our designs.

In writing *Underground Excavations in Rock* almost 15 years ago, Professor E.T. Brown and I developed the Hoek-Brown failure criterion to fill a vacuum which we saw in the process of designing underground excavations. Our approach was entirely empirical and we worked from very limited data of rather poor quality. Our empirical criterion and our estimates of the input parameters were offered as a temporary solution to an urgent problem.

"The fact that the criterion works, more by good fortune than because of its inherent scientific merits, is no excuse for the current lack of effort or even apparent desire to find a better way."

In retrospect it is clear that we were naive in believing that our "emergency" criterion would soon be replaced by a set of well-researched predictive tools which were adequately substantiated by field studies and back analyses of real rock engineering case histories. In fact the reverse has happened and I am alarmed to see the Hoek-Brown criterion being applied to problems which we did not even dream about when we made those desperate estimates 15 years ago.

The fact that the criterion works, more by good fortune than because of its inherent scientific merits, is no excuse for the current lack of effort or even apparent desire to find a better way. It is my hope that this short note may catch the eye of someone who has the skill and the motivation to pick up the challenge and to lead in the development of better tools for providing us with the input data which we need for rock engineering designs of the future.

FIRST ANNOUNCEMENT

2nd North American Rock Mechanics Symposium (NARMS '96): Tools and Techniques in Rock Mechanics

An Invitation to Montreal, Quebec, Canada, June 19-21, 1996

The Second North American Rock Mechanics Symposium will be held in Montreal, from June 19 to 21, 1996. The Canadian Rock Mechanics Association, U.S. National Committee on Rock Mechanics, and Sociedad Mexicana de Mecanica de Rocas, representing the countries of North America, have established the North American Rock Mechanics Symposium (NARMS) to promote the synthesis of diverse rock mechanics activities in professional societies, academia, industry and government throughout North America. It aims to provide a forum for technology transfer, discussion and re-assessment of the latest theory and practice in the area of rock mechanics in mining, civil and petroleum engineering. It deals with major aspects of rock mechanics research, development and practices, in an effort to bridge the gap between theory and practice, while providing guidelines for future endeavors. The Symposium consists of keynote addresses, technical sessions, workshops and short courses. It will also include exhibitions, and pre- and post-conference field tours. We hope to see you in Montreal.

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Le deuxième Symposium nord-américain de mécanique des roches se tiendra à Montreal, du 19 au 21 juin 1996. Les groupes nationaux du Canada, des Etats-Unis et du Mexique ont créé ce symposium afin de promouvoir la synthèse des diverses activités nord-américaines de mécanique des roches. Commandité par l'lnstitut canadien des mines et de la métallurgie et organisé conjointement avec l'Ecole Polytechnique de Montréal et l'université McGill, le symposium de Montréal comprendra des sessions plénières, des sessions techniques, des séminaires, des cours intensifs, une exposition et des visites techniques. Nous espérons vous y accueillir.

El segundo Simposium norteamericano en mécanica de rocas se efectuará en la ciudad de Montréal, del 19 al 21 de Junio de 1996. Los grupos nacionales de Canada, Estados Unidos y Mexico han creado dicho simposium afin de promover la sintesis de las diversas actividades norteamericanas en mecanica de rocas. Patrocinado por el Canadian Institute of Mining and Metallurgy, y organizado conjuntamente con la Ecole Polytechnique de Montréal y la universidad McGill, este magno evento que se llevara a cabo en la ciudad de Montreal comprendera sesiones plenarias, sesiones tecnicas, seminarios, cursos intensivos, una exposicion y visitas tecnicas. Esperamos recibirlos.

Commission on Swelling Rock

Annual Report 1993–1994

H.H. Einstein, Commission President

1. Work Completed

The two documents:

- ❖ Suggested Methods for Rapid Field Identification of Swelling and Slaking Rocks
- ❖ Comments and Recommendations on Design and Analysis Procedures for Structures in Argillaceous Swelling Rock

have gone through the final review and were sent to the ISRM Secretariat for publication.

A meeting was held at EUROCK '93 in Lisbon with a great deal of discussion and exchanges of opinion. The tasks in progress were reviewed and progress was considered satisfactory.

2. Work in Progress

Task 1: Mineralogical and texture/fabric evaluation of argillaceous and anhydritic rock

Chairman: R. Nüesch

Members: P.B. Jadhav, F. Madsen, R. Martin, G. Mesri. Both R. Nüesch and P.B. Jadhav have been working on this. A draft is still due.

Task 2: Stress-strain testing of anhydritic rock

Chairman: F. Madsen

Members: N. Bischoff, D. Kirschke, R. Nüesch, P.N. Sundaram.

F. Madsen completed the first draft of the document "Suggested Methods for Laboratory Testing of Rocks Containing Clay and Anhydrite." The draft was sent out for review in early spring 1993. The reviews came in throughout 1993. They recommend only minor changes. F. Madsen and H.H. Einstein discussed this at one of their regular meetings and it was decided to send this document to the publishers in the near future.

Task 3: Aspects of tunneling in anhydritic rocks

The idea is to come up with a list of problems and questions that need to be addressed, such as:

- ❖ Present procedure for designing tunnels in anhydritic rock
- ❖ Collection of case histories in Southern Germany and Switzerland
- ❖ Sensitivity/parametric studies with selected analytical swelling rock models

Chairman: M. Gysel

Members: G. Anagnostou, E. Fecker, J.R. Kiehl

Technical disagreements still persist. New research now underway in Switzerland and Germany may provide some answers.

Task 4: Analysis and design of structures *on* argillaceous swelling rock (foundations, slopes, retaining structures)

Chairman: R. Yoshinaka

Members: See below

The Japanese colleagues in the Swelling Rock Commission, together with the Commission on Soft Rock of the Japan Society of Civil Engineers (Mr. Tanaka, Chairman), are collecting and evaluating data regarding swelling and slaking problems affecting foundations, slopes, retaining walls, etc. A report on this topic was received at the 1993 Commission meeting. For this year's meeting in Santiago, we received a "sample case history." The collection promises to be a very useful document for practicing engineers.

3. Conclusions

Progress in 1993-94 was not as rapid as expected. An effort will be made to be more productive in 1994-95.

Commission on Education

Multimedia in Rock Mechanics Training

Christopher R. Windsor and Alan G. Thompson

Abstract

The objective of this brief discussion is to provide a summary of a report we have prepared on this rapidly developing technology for the ISRM Commission on Education. We will briefly explore what multimedia is and what hardware and software are available. We shall also take a brief look at a simple multimedia course designed by a team of novices for teaching students about Rock Reinforcement. A review of some of the lessons and mistakes made in preparing this course may serve as an aid to others contemplating a multimedia approach to training or technology transfer. A copy of the complete report is available from the authors.

1. Introduction

The International Society for Rock Mechanics' Commission on Education is currently working on a rock mechanics curriculum guide and is also undertaking a program of preparing collections of slides, video tapes, computer programs and a bibliography of rock mechanics books. This work and extensions of it are necessary in order for our Society to guide educators towards a uniform and proper approach to rock mechanics teaching. The work is also timely because Rock Mechanics has grown to be a popular and useful subject in civil, mining, geotechnical and geological engineering education throughout the world. The rewards are a well-informed and balanced profession with a common, unified understanding.

A small component of this commission activity concerns the methods of teaching and transferring rock mechanics technology within the profession. Conventional methods of information transfer have included formal lectures, seminars and workshops and the prescribed reading of textbooks, papers and written reports. Presentations have generally been found to be more effective than written works. However, presentations can become ineffective and cumbersome if they are not carefully prepared and delivered. Furthermore, they require the attendance of an expert presenter and they cannot usually cater to the different rates of progress and retention capacities of the various members of the audience. An alternative, or complementary approach, is now possible using personal computers and the emerging technology of multimedia.

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Multimedia currently has many definitions and its technology is changing so rapidly that it is difficult to provide a rigorous definition that will not be found inadequate within a relatively short period of time. The term will probably end up meaning something like "a technology for the convergence of computers, telecommunications and publishing to produce an integrated static (text and graphics) and dynamic (audio and video) information system." For the present, and for the purpose of this document, the meaning is taken as an amalgamation of computer hardware and software to convey information in the form of text, graphics, sound, video and digitized images. The ubiquitous use of the personal computer, the development of suitable peripheral hardware devices and the advent of multimedia development software mean that it is now possible to augment traditional methods of teaching with computer based interactive training courses. The multimedia "lectures" still need to be carefully prepared and choreographed but the finished product can be arranged to complement and enhance a conventional course of lectures.

2. Multimedia and the Transfer of Information

Multimedia has many applications apart from teaching, training and technology transfer. For example, it is now being used as "touch screens" to provide information at the entrance to large department stores, organisations and civil amenities. In this form it is an alternative to a help or an enquiry desk. It is also finding use as interactive sales brochures and catalogues with on-board sound and animation to display and promote products. Other applications include fully-prepared presentations, electronic books, newsletters and journals. For example, in the United States the popular magazines *Newsweek* and *TIME* are already available in a multimedia format on CD-ROM.

Before the advent of certain PC operating environments such as Microsoft's Windows 3.1, the Apple Macintosh system and IBM's Ultimedia, it was very expensive and difficult to develop a multimedia application. Such an investment needed an assured and large user market. The general family education/information area and the basic child education area are examples of such markets and were worthy of exploitation by initial multimedia developers. Now, with the Windows 3.1 system and its seamless integration of so many development tools being a standard component of PC computing, the possibility of developing a multimedia application is within reach of all educators or practitioners wishing to transfer information to a target audience. While the information needs to be carefully prepared and skillfully choreographed, the finished product enjoys many advantages over other methods of information transfer.

Studies have been conducted that compare interactive multimedia training with traditional classroom based training and some of the results are startling. For example, results indicate up to 46% increase in retention, more than 300% increase in subject mastery and more than 50% reduction in required learning time (Select Learning, 1993). These positive comparisons are most likely due to the trainee controlling the speed of information transfer. They suggest that digesting and understanding some components of a course of study might, in many respects, depend on the individual and that courses may be more effective when conducted on an individual rather than a group basis.

When it comes to teaching rock mechanics subjects to students it may be more helpful to think of multimedia as an adjunct to teaching that could be used to handle and disseminate bulk information or information of a sub-critical nature. For example, consider the following possibilities:

1. A short, introductory primer course for each rock mechanics subject that students must study prior to formal lectures. This would allow for students of different backgrounds to enter the start of the formal course at a common level.
2. Tutorial exercises and a detailed, clear explanation of how to solve tutorial problems in a sequence of well-defined steps using simple graphics and text. This could accommodate various speeds of comprehension without any disadvantage to either the slower or faster students.
3. Expanded course scope or increased complexity of the subject matter in optional extension modules for the more advanced students.

Formal undergraduate and postgraduate courses are probably the most important components of the rock mechanics teaching and training problem. However, there are many other circumstances in which there are demonstrable needs to teach rock mechanics subjects to students or workers in allied fields. For example, rock mechanics has been, and still is, considered something of a specialist subject in many universities. Consequently, some university personnel may wish to briefly touch on the subject as a component of the curriculum but do not have the means or the expertise to teach the topic. Furthermore, many practising professionals in civil engineering, mining engineering and geology are very keen to learn about topics in rock mechanics but have not had the opportunity to study the subject as part of their undergraduate courses. It often happens that professionals in these disciplines are based remotely from the centres of education and may not be able to attend specialist courses. For example, in the mining industry it is now common for on-going training to be an integral part of employment. Many mining companies would benefit from their engineers and geologists having access to a computer-based rock mechanics training course that could be run on site and at their discretion. The concept of a standard course for employees leading to a uniform understanding across an industry offers many logistic and economic advantages over conventional teaching.

3. Multimedia Technology

The technology of multimedia can be divided neatly into two components: hardware and software. Multimedia hardware includes the computers, computer peripherals and associated equipment. Multimedia software is taken here to mean the pre-packaged courses or programs and the auxiliary development and preparation software needed to create a multimedia application.

3.1 Multimedia Hardware

The capability of the computer hardware dictates the limits of a multimedia application. Much of the hardware in current use (PCs, CD-ROMs, Sound Cards and Video Frame Grabbers) has been available for some time. However, hardware compatibility and a standardised methodology were required by the industry.

To address this problem the Multimedia Personal Computer Marketing Council was set up in 1989 by the IBM, Microsoft and Tandy corporations. Its role was to establish a specification that will guarantee compatibility and encourage software vendors to develop multimedia software. The result was the MPC Specification Version 1.0 released at the Multimedia Developers Conference in November, 1990. The Multimedia Personal Computer (MPC) standard indicates the minimum PC configuration needed to develop and run multimedia software. The MPC Marketing Council is now managed and coordinated by the Software Publishers Association (SPA) in Washington, DC. Some time ago (Microsoft, 1992) detailed the minimum configuration for hardware and software. The MPC standard has since been updated to include a Level 2 specification. A Level 2 MPC would now comprise a 25 MHz 486SX processor, 4M RAM, 160M drive, 16-Bit Sound card, 64K colours on 640 by 480 pixel resolution display and an XA (Extended Architecture) compatible CD-ROM.

These recommendations provide hardware and software configuration guidelines only. Such systems will provide much, if not all, of the hardware that the multimedia developer and user might need. However, more advanced and specialised systems than these can certainly be assembled. By the same token, less complicated systems can also be used for multimedia. In fact, it is worthwhile bearing in mind that a well conceived and carefully scripted application that gives information in terms of text and graphics on a basic PC has a greater educational potential than a poorly prepared application running on a high-tech, state-of-the-art, MPC system.

In other words the spectrum of multimedia applications is wide and the term should certainly not be thought of as a concept restricted to the latest hardware. There are, however, penalties for developers and end-users in attempting to use multimedia with the simple PC configurations. These penalties are mainly associated with the capacity to store and manipulate large amounts of information and the speed and resolution of presenting that information. In fact, these basic tasks present problems with all systems and are discussed in detail along with data formats, compact disk technology and the role of data compression technology in the full report.

3.2 Multimedia Software

With the advent of the MPC Specification software houses are now developing a large range of multimedia applications and development utilities. Basically, multimedia software can be divided into three classes:

1. Pre-packaged Applications
2. Presentation Software
3. Authoring Software

Pre-packaged applications include Microsoft's Bookshelf, Beethoven and Cinemania and more advanced applications like Microsoft's "Encarta" and "Dinosaurs" and the San Diego Zoo's "The Animals." After viewing packages like these it will become clear that the range of possible applications and presentation style for multimedia is limited only by the imagination of the developer.

The traditional forms of presenting information can now be augmented by the second class of multimedia software comprising presentation software packages. These enable a concise and colourful presentation to be choreographed as a sequence of frames that may be displayed on a PC. Such a presentation is usually not fully interactive and does not necessarily need to include video or sound. However, it may still be termed multimedia and can be both dynamic and interesting.

Authoring software or authorware is a collective term used to describe the third class of multimedia software which is used to develop professional interactive computer applications. There is now such an extensive array of authorware products available that the choice of the most suitable software usually presents quite a difficult problem for the inexperienced multimedia developer. The new developer may be tempted to simply purchase an authorware product on the basis of an example application used to publicise or demonstrate the package. However, many multimedia applications are produced by large, experienced and well-equipped software development teams—such an approach may not be possible for all prospective developers. The key to choosing the most suitable authoring software is based on knowing:

a. What is the type, style and extent of the application to be developed?

b. What hardware constraints apply to the developer and the end user?

c. What particular software facilities are needed to prepare the application?

Only when questions like these have been answered will it be possible to conduct a meaningful review of the available authorware software. The features to look for and the review process we found useful is discussed in detail in the full report. The best approach to choosing a suitable package is probably to seek expert advice or to study the expert reviews and advice that appear in the multimedia journals such as MPC World, Multimedia World and New Media.

4. A Simple Example of a Multimedia Course

The CSIRO Rock Reinforcement Group conducts research into stability assessment and stabilisation procedures for rock excavations, predominantly for the Australian mining industry. One of the problems with this type of work is to find and manage a method that can effectively transfer existing and new technology to this industry. The group recognised the possibilities and advantages of a multimedia approach to this problem in 1989 and has since developed a simple interactive computer-based training course for Rock Reinforcement Practice. At that point in time the available multimedia hardware and software was relatively primitive compared with what is currently available. However, it is hoped that a brief description of the course developed, the learning and decision-making processes the group had to go through, some of the development principles discovered and some of the lessons that were learned may be of general use to others contemplating the development of a multimedia course for a mature audience.

After reviewing the available hardware, development software and taking into account our particular industrial requirements, the group made a choice of the basic hardware platform and software. In our case, we chose the simplest hardware system and authoring software that enabled the course to be distributed without incurring additional costs.

4.1 Programming and Development Features

The course was developed in a complete object-oriented environment that included an extensive "scripting" or programming language. The scripting language was similar to other programming languages and included features such as arithmetic and text functions, control structures and commands for file handling and data management. It also included many other features common to Windows compatible software such as mouse control, drop down menus, scroll boxes, buttons and hotwords. Our experience showed that the scripting language was relatively easy to learn for programmers with working knowledge in scientific languages such as FORTRAN, BASIC and PASCAL. Programmers with experience in another language such as C would also find a scripting language simple to learn.

Many of the scripting capabilities were required to develop and provide the features described in the following two sections. The scripting language enabled us to develop a relatively extensive course. Large text files included in the course are accessed as required by the control program—that is, the text is not permanently integrated within the course. This means that the control program is shorter in length and also allows the text files to be easily edited in isolation from the control program. Other course content such as computer sketches and images are also stored on files. All these files are carefully catalogued as they need to be linked with labelled pages in the control program.

4.2 Operating Principles

After considering a number of important points that form the basis of the next section, the group went through a sequence of planning stages and developed the user interface shown in Figure 1. The interface divides the computer screen into three separate areas:

1. The User Control Area.
2. The Passive Information Area.
3. The Active Information Area.

The User Control Area occupies the lower left part of the screen and is used for control and flow of the course. The eight buttons provide for single screen forward and backward, fast forwards and backwards, a help facility, an index and a map. The index returns the user to the start of the course which also happens to be the screen shown in Figure 1. The map shows a large flow chart of boxes representing all the chapters, sections and subsections of the course. A highlighted box in the flow chart indicates the current position in the course.

The Passive Information Area occupies the upper left part of the screen and is used to provide information on valid user actions, help and any extra, context-sensitive information. The only user interaction allowed for in this region is provided by a scrolling system along the right hand edge of this area.

The Active Information Area occupies 75% of the screen and is used to display the notes, tables, text, technical drawings, sketches, captured images and so on that make up the course content. This area is interactive in that additional course control is provided by selecting "hotwords" that may occasionally be found within text or selecting "hot regions" that are occasionally

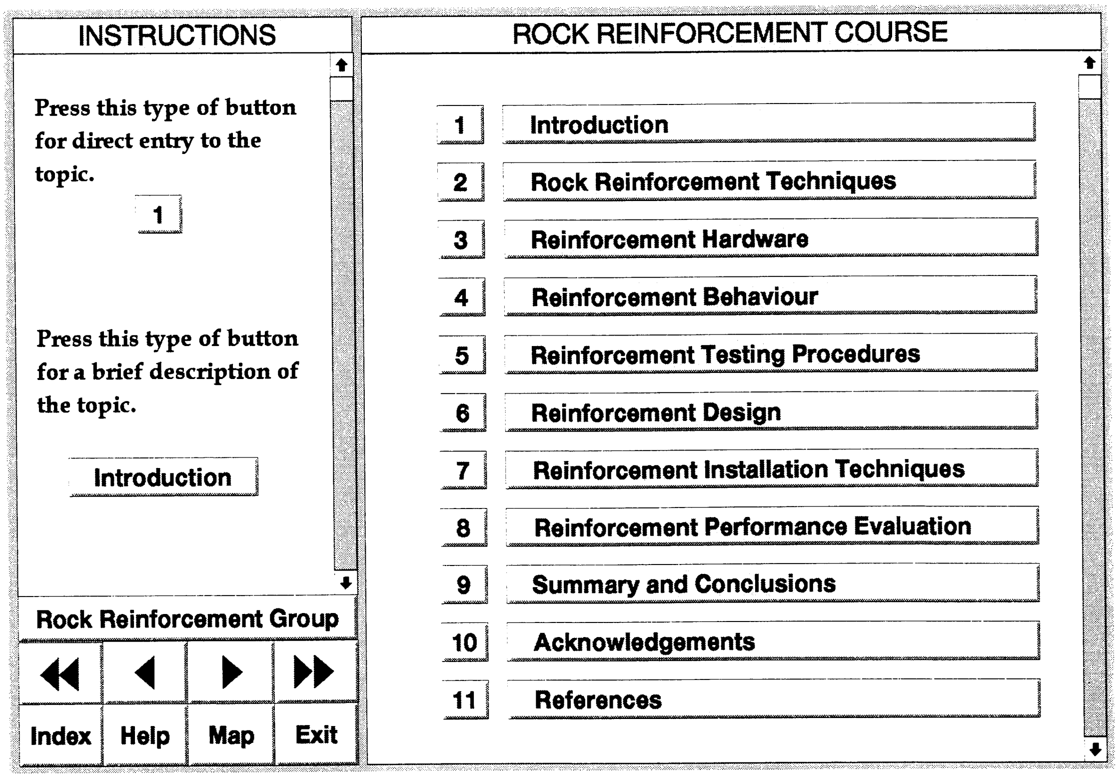

Figure 1. User interface for multimedia rock reinforcement training course.

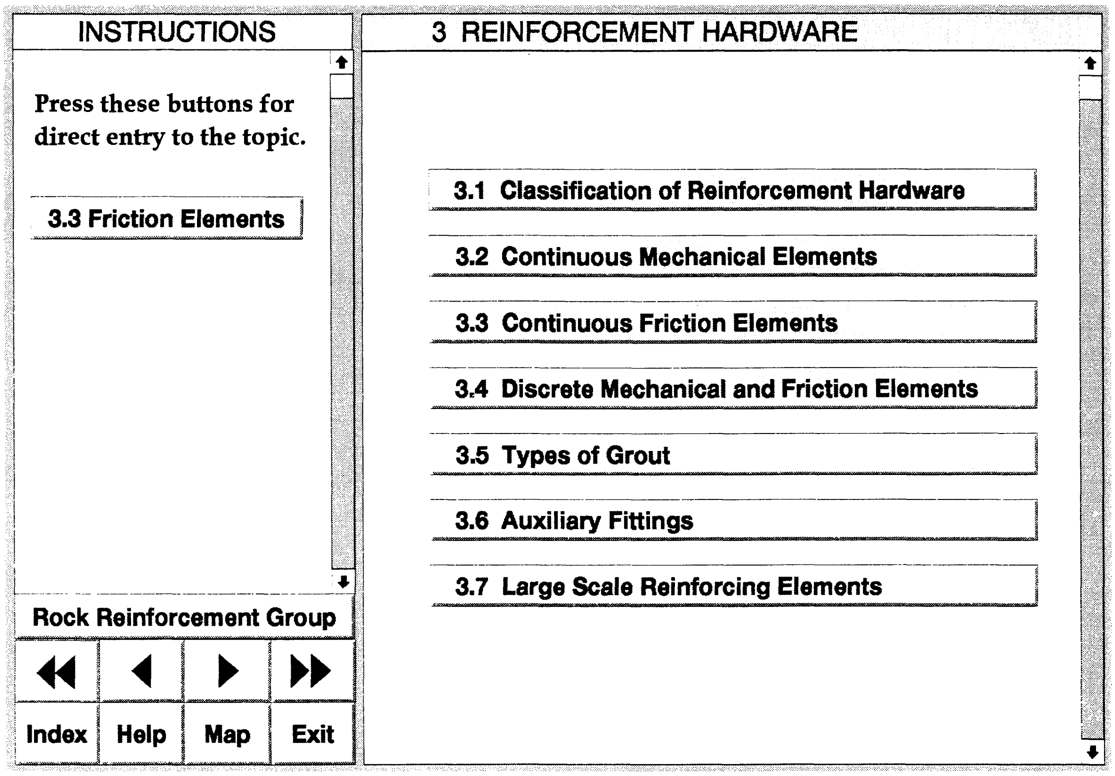

Figure 2. List of sub-sections in section 3 that were accessed directly from main index.

found within graphics. A scrolling system is also provided along the right hand edge of this region.

An appreciation of the operation of the passive and active regions can be obtained by referring to Figure 1 and Figure 2. In both of these particular circumstances the Passive Information Area indicates the operation of two types of navigation buttons in the Active Information Area. To progress to the screen shown in Figure 2 the user has depressed the button marked [3] in Figure 1. An example of a bit map image of a simple technical drawing and an explanatory note are given in Figure 3.

4.3 Assessment Procedures

It was anticipated that there would be multiple users of our course; possibly on the one PC. Hence, a user registration and bookmarking feature was added to the course. Each user's name is used for unique identification. This enables the last page accessed in the course to be stored with the user's name on file as a bookmark. The bookmark is used to allow the user to resume at the same page in a subsequent training session. This facility can also be extended to keep a history of the pages accessed by the user and the time spent on each page. This information could be used to ensure that the user has made a reasonable effort towards reading the information provided in the various sections of the course.

Assessment is provided using a question and multiple-choice-answer type test. An example of this is shown in Figure 4. While the test is in progress, access is denied to the information contained in the training course. In this manner, a self-contained training course with complementary assessment can be provided. This minimises the interaction required from an in-house training officer or from a representative of an external training organisation.

4.4 Planning a Multimedia Training Course

In developing the multimedia training course described in the preceding sections, we could not find any guidelines to follow. However, it was recognised that a structured approach was required in the development of the user interface and the content of the course. A number of the steps in our approach were found to be crucial and some valuable lessons were learned by making mistakes. Based on our experience, a sequence of steps and decisions are recommended for the development of a multimedia training course. These steps can be broadly classified as preliminary planning, selection of the hardware and software, design of the course and its content, implementation and, finally, appraisal and distribution. The individual steps are:

1. Identify the need for a training course.
   Identify the target audience (e.g., academic or industrial)
   What is the scope and extent of the course?
2. Decide on the fundamental aspects of the proposed course.
   Does it require sound, animation and video?
   Will it require intensive user interaction?
3. Review the operating hardware generally

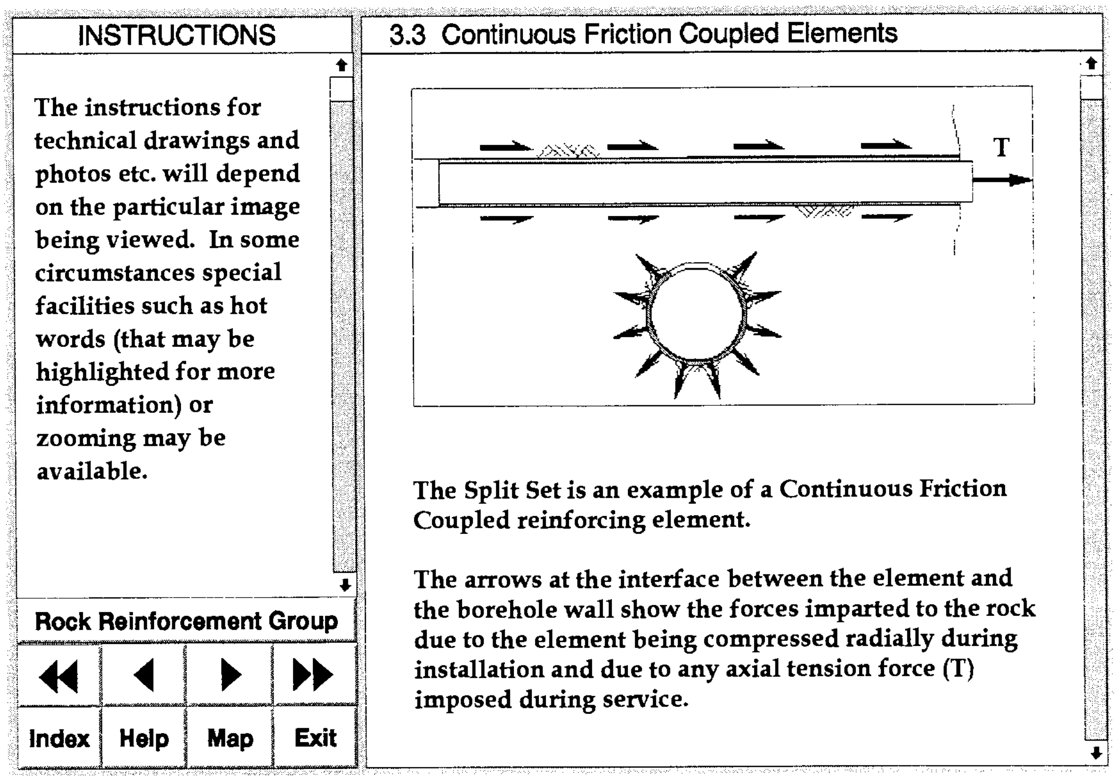

Figure 3. Bit-map image of a simple technical drawing incorporated into the training course.

available to the target audience.
(i.e., PC based system, work station or network?)

4. Review the available multimedia development software.
(i.e., consider the development environment, on-board facilities for creating and importing material and your skills at learning and using the scripting language.)
5. Review the compatibility of the previous three concepts with your current facilities for preparing text, graphics, images, video, etc.
(i.e., you have to ensure that you can pre-

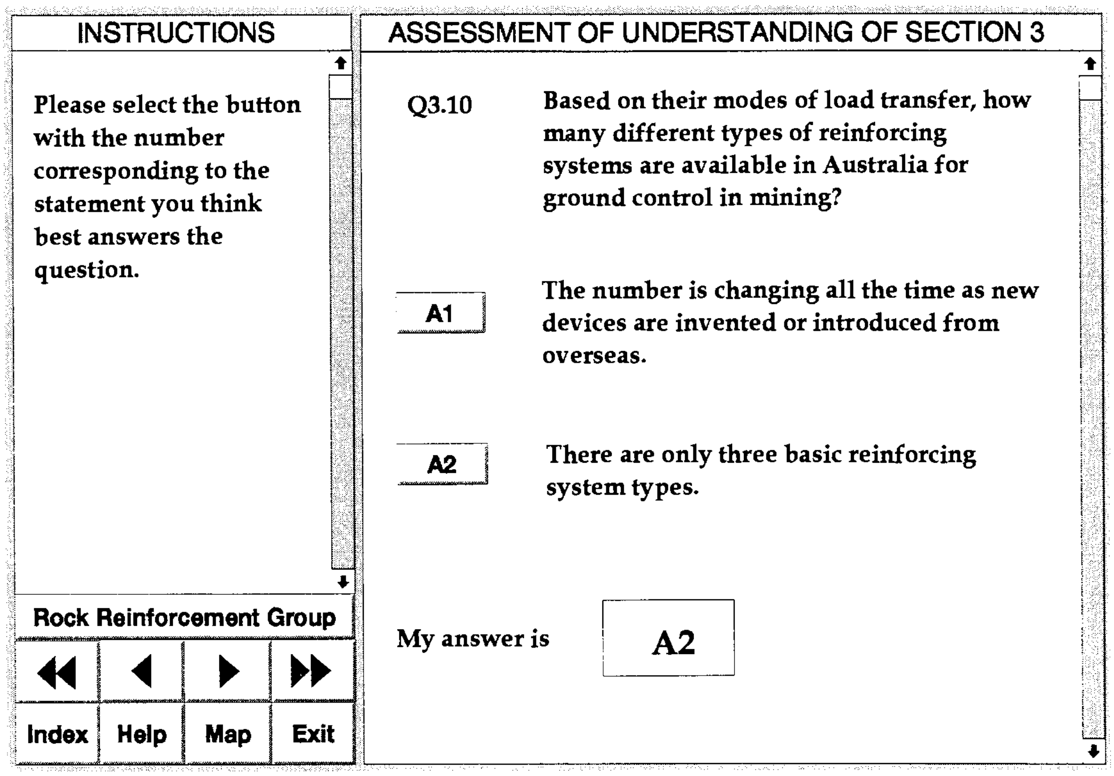

Figure 4. Typical assessment page with question and multiple choice answers.

pare, import and present the content)

6. Decide if the course is to be free of any run-time costs.

   (i.e., some development software may attract a run-time license and fee for each user.)

7. Purchase the required authoring software and any peripheral software (e.g., word processing, graphics preparation) and hardware devices (e.g., scanner for existing text, graphics or photographs)?

8. Design a standard "Front End" or "User Interface" for your course.

   (i.e., The course user will need to become familiar with accessing your course and will be comforted by a design that is consistent and maintains active and passive regions of the interface in fixed positions on the screen. The user interface is one of the most important design aspects to get correct.)

9. Design a standard operating system of buttons or keystrokes.

   (i.e., the operation of the course should not require a manual. The buttons and hotwords or keywords should enable unambiguous navigation throughout the course and simple retrieval and viewing of information. Remember that the course may be used by persons who are not computer literate and who may even be computer shy. A minimum number of buttons should be used. Further, the buttons should appear in consistent positions and be unambiguous. For text and images, the user should be able to progress forwards and backwards by individual frames and sections. For video and sound, the user should be able to stop, pause, rewind and fast forward play.)

10. Select a standard text font, text sizes and hierarchy, a palette of standard foreground/ background colours and display sizes.

    (i.e., some text sizes, fonts and colour contrasts cause eye strain. Furthermore, some colour combinations are unsuitable for drawings and graphics. Some fonts may depend on the hardware configuration and some images and photographs have to be presented at minimum resolutions)

11. Prepare some sensible rules limiting the amount of information displayed on the screen.

    (i.e., the screen should not be completely filled with text, drawings or a multiplicity of different windows)

12. Decide on a balance of text to images throughout the course.

    (i.e., do you wish to present the course in the style of a scientific paper or a magazine article?)

13. Design a filing system that can handle both the hard copy and soft copy content.

    (i.e., the course content may become large and you will need a well conceived strategy to label, file and retrieve text, graphics etc.)

14. Decide on the age, experience and environment of the target audience.

    Are the trainees semi-skilled, undergraduates or graduates?

    Will the course generally be run in a classroom, office or at home?

15. Design and prepare the course and contents as a hard copy version and then convert it to computer files.

    (i.e., text, graphics, images etc.). Note that the course contents should have really been totally prepared before this step but this implies prior knowledge of the exact extent and limitations of the application you will end up with.

16. Prepare a robust on-line help system or use a "hypertext" approach to provide the user with extra information on demand. A hypertext approach is really a type of referencing system that allows the user to get extra information on particular "hot words" or jump to a related topic. The hot word is chosen and a pop up display gives extra information or allows transferral to a related area of the application.

17. Determine whether the course will form the basis of accreditation for competency purposes or will fulfill the requirements for some form of training levy. If it will, then the operating procedure may also need to cater for multiple users, "bookmarking," time keeping and assessment.

18. Design an assessment procedure that will test the course user's knowledge and understanding.

19. Test the operation of the product on the equivalent configuration hardware available to the user not just on the developer's hardware. Also, test the content of the course using an independent reviewer from the same discipline.

20. Decide on a distribution medium. In most circumstances the assumption of whether the user will access the course by floppy disks or compact disks would have been made at point 3 above. However, this, and your choice of distribution may change with time. If you choose a floppy disk target audience then the course content must be brief and "media lean" and you must consider methods of data compression. If you choose CD-ROM many of the storage problems are eased but your target audience may then be limited by their available hardware.

4.5. Logistics and Costs of Course Production

The development of the main operating system took place as a part-time group activity in parallel with several other tasks. The process of designing the layout of the template (or user interface) and the requirements for data file naming conventions and data structures was completed over several months with an estimated total input of 150 person hours. The programming of the course control and associated features was completed in about one month with total input of about 120 person hours. Text files are prepared in ASCII format directly from word processor document files. Graphical sketches and computer images are prepared using commercial packages. Approximately 30 minutes is required to prepare the files in suitable formats from these packages and to add the necessary scripting code for each new page in the multimedia course.

It is expected that the market for multimedia courses will depend on the precise nature of the course content. Our current course is of a practical nature and is intended for use by both final-year geology and civil and mining engineering students and site personnel. Our intended market therefore includes tertiary institutions and companies involved in both surface and underground rock excavations for civil and mining projects.

We believe that the funding of the development of multimedia courses is limited to about three sources. The funding of the development of our course was obtained directly from a number of individual organisations associated with the mining industry in Australia. Also, the course development forms only a part of the total work program within a larger research project. Other possible sources of funding in the future could be through direct education or industry training grants or the recovery of development and distribution costs through commercialisation. This last option is the least preferred one from our point of view as it unduly restricts distribution. By keeping distribution costs to an absolute minimum, it may be possible for students to purchase multimedia courses in much the same way as they now purchase reference books.

The CSIRO Rock Reinforcement Group is probably typical of many groups and educators now considering using multimedia in technology transfer, training and education. We developed the above system to suit our particular circumstances and the approach we used has now to some extent been superseded. However, the simple example course and the sequence of development steps we have recommended should hopefully stimulate thought on how to approach the task of preparing a multimedia course. Fortunately, professional multimedia developers are now starting to write books and journal articles to help the new multimedia developer. The useful journals include *MPC World, Multimedia*

World and *New Media*. Some useful books include *Technology Edge: A Guide to Multimedia* published by New Riders Publishing; *Multimedia Interface Design* published by Addison Wesley; *The Visual Display of Quantitative Information* published by Graphics Press and *The Windows Interface: An Application Design Guide* published by Microsoft (supplied with the Windows Software Development Kit). For those with access to a MPC or a CD-ROM drive, *The Guided Tour of Multimedia* developed on a CD by Zone Publishing is also recommended.

5. AREAS FOR FUTURE INVESTIGATION

If multimedia is to become the convergence of computers, publishing and telecommunications as current trends tend to suggest then it would appear wise for all professionals to take it upon themselves to stay in touch with the rapidly developing hardware and software products. It is suggested that each member working in the area of rock mechanics education make an effort to stay abreast of this emerging technology. A summary update of the state-of-the-art in the ISRM *News Journal* every year may help this situation.

It is highly likely that multimedia, or an evolution of it, will greatly affect our approach to teaching and the transfer of information within the profession. If this notion can be accepted then a number of questions should be asked of the profession:

1. Do we wish to see a minimum standard course for each subject in rock mechanics prepared using multimedia? For example, should a selection of ISRM Approved courses be developed for underprivileged students or professionals in allied fields that are seeking additional information?
2. Do we wish to see a standard method of digital communication between researchers, developers and educationalists? For example, do we wish to be able to share files (i.e., standard quality, standard size drawings, graphics, photographs) for the preparation of courses, reports and presentations?
3. Do we wish to have a standard format for the publication of scientific and engineering documents and a standard bibliographic and referencing system?

The possible questions are limited only by the imagination. However, in essence they all come down to making decisions regarding a unified approach to transfer of educational and technological information within the profession. The question is not "What can multimedia achieve for the ISRM?" but "How does the ISRM wish to operate within this new technology?"

6. CONCLUSIONS

The objectives of our report were to provide an overview of the rapidly developing technology called multimedia and to suggest how it might be used in rock mechanics education and training. An attempt was made to define the topic, review and briefly describe the available hardware and software and to explore the ways of arranging this technology for optimum effectiveness.

A simple example multimedia course designed by a team of novice developers for teaching students about rock reinforcement was described. A review of the process of developing that course and some of the mistakes made and the lessons learned provide some simple rules and a sequence of course development steps. These should serve as a starting point for others contemplating the development of a multimedia training course. Finally, some of the issues that should probably be considered by the Rock Mechanics profession were listed. A brief examination of these issues results in the single notion that the adoption of a standard approach for the storage, transfer and presentation of all types of media information within the profession might prove to be judicious.

ACKNOWLEDGEMENTS

The authors would like to thank their colleagues in the CSIRO Rock Reinforcement Group, in particular, G. Cadby, P. Carden, W. Robertson and R. Thompson, for their help in developing the rock reinforcement course.

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Recent Ph.D. Theses in Rock Mechanics

Dept. of Civil Engineering, University of Colorado, Boulder — Theses directed by Prof. B. Amadei

[Supervisors are invited to submit a short (half-page maximum) abstract of recently completed Ph.D. theses, in the style of the two printed below.]

Gravitational and Tectonic Stresses in Anisotropic Rock Masses with Irregular Topographies

Ernian Pan (Ph.D., Geophysics/Civil Engineering)

Knowledge of the in-situ state of stress is important in many problems dealing with rocks in civil, mining and petroleum engineering as well as in geology and geophysics. Stresses in rock masses consist of natural stresses (gravitational and tectonic) and man-induced stresses. Although natural rock stresses can be regionally uniform, they also can be locally perturbed by such factors as surface topography, excavation, injection, etc.

In the past, two types of analytical methods have been proposed in the literature to model the influence of topography on in-situ stresses: the exact conformal mapping method and the perturbation method. The former is restricted to isotropic rock masses and simple topographic profiles for which conformal mapping functions can be found. The latter is limited to topographies with small slopes not exceeding 10 percent. In view of these limitations, existing analytical methods can have limited applications in engineering practice.

This thesis presents a new analytical method to evaluate the combined effect of rock anisotropy and topography on in-situ stresses. The rock mass can be generally anisotropic, orthotropic or transversely isotropic, and can be limited by any irregular (but smooth) topography. The rock mass can be subject to gravity, tectonic and surface loads. In deriving the new analytical method, the closed-form solution for the gravitational stresses in a general anisotropic half space with a flat surface is combined with the analytical function method of anisotropic elasticity to express the stresses in terms of three analytical functions. These three functions are then obtained using a numerical conformal mapping technique and an integral equation method.

Numerical examples illustrate the dependence of gravitational and tectonic stresses on such factors as: topography, orientation and degree of rock anisotropy, and surface loads.

Finally, it is shown how the new method can be used in engineering and geophysics. For example, it is shown how it can provide guidance in the design of underground excavations in rock and predicting the stability of slopes in layered rock masses. Also, it is shown how the new method can provide geophysical insight into the effect of anisotropy and topography on in-situ stresses at the local and regional scales.

Experimental and Numerical Modeling of Shear Socketed Piers

Aziz Khan (Ph.D., Civil, Environmental and Architectural Engineering)

During the past two decades the use of socketed pier foundations has rapidly increased as they proved to be an economical method for transferring heavy loads to the surrounding media. The foundation material can vary from hard rocks with high strength to very soft and weathered rocks with properties of stiff clay or dense sand. The nonlinear behavior of socketed pier foundations is controlled by a number of fundamental factors (e.g., rock mass modulus, stiffness of both the piers and the surrounding media, roughness of pier-rock interface, geometry of the embedment etc. . .). Design of rock foundations is primarily an empirical process. There is no single design method available, to date, that incorporates all the basic factors.

This dissertation is a step towards a better understanding of the nonlinear behavior of piers in discontinuous and soft rocks. A detailed laboratory investigation was carried out. Model piers socketed into hydrostone were tested to assess the shaft resistance of piers in soft rocks. Hydrostone was used to simulate rocks of very weak to medium strength and plane concrete was used to construct the piers. The influence of (1) the relative stiffness of the piers with respect to the surrounding rock material, and (2) the roughness of the pier-rock interface, on the overall pier behavior was investigated. In addition, direct shear tests under constant normal load were carried out in order to measure the shear and dilatancy behavior of the concrete-rock interface.

A plasticity-based interface model was implemented in an existing finite-element program. Various features of the model such as failure criterion, plastic potential, bond degradation and dilatancy were presented. The model was used to simulate the interaction between concrete and rock numerically. Comparison between numerical predictions and laboratory observations was conducted.

NEWS FROM THE ISRM SECRETARIAT

ISRM Board Meeting May 8 & 11, 1994, Santiago Chile

The Board of the Society met in Santiago, Chile on May 8 and 11. The meeting, chaired by the President of ISRM, was attended by the Vice-Presidents of the geographical areas (Africa, Asia, Australasia, Europe, North America and South America), the Secretary-General of the Society and the Contributing Editor of the *News Journal*.

The agenda of the ISRM Council Meeting, to be held the following day, was discussed, and recommendations were prepared for the decisions to be taken. Each Vice-President presented a summary report for his region relating the activities developed and the problems faced. The impossibility for some groups of colleagues to organize effectively, due to problems of a national or geographical level was raised. After a lengthy discussion, the President recommended that a Guideline be drafted to govern the admission of Groups other than National Groups.

Financial Report

The report on the financial situation of the Society was analysed and discussed and the Board recognized that thanks to the recent increase in membership fees, the Society is again on a sound financial footing.

Statute Amendment

A recommendation to the Council was prepared including an amendment to the ISRM Statutes and By-Law No. 2 to permit the ISRM President to be elected two years before the Congress in which he/she takes office. Such a policy will enable a certain overlap of the successive Boards and avoid the risks of ruptures in the ISRM activities, thus promoting a smoother transition between the policies defined and implemented by each Board.

Details of the organization of the 8th ISRM Congress were discussed with the Congress Organizing Committee.

1995 Rocha Award

The Board, acting as the Rocha Award Committee, selected the prize-winning Ph.D. thesis for 1995. The Award Committee's choice was the thesis entitled "The Strength of Massive Lac du Bonnet Granite Around Underground Openings" submitted by Dr. C. Derek Martin, Canada, to the University of Manitoba, Winnipeg Canada, and approved in November 1993.

ISRM COUNCIL MEETING 1994

The Council Meeting was held in Santiago, Chile on Sunday, May 9, and was organized in conjunction with the ISRM International Symposium on "Integral Approach to Applied Rock Mechanics."

All Board Members, with the exception of the Vice-President-at-Large, Dr. R. Widmann, and one Past-President, were present. Twenty five of the forty one current ISRM National Groups were represented (twenty in person and five by proxy). Invited observers representing the ISRM Commissions and allied Societies also attended the Meeting.

The Council made the following decisions:

- ❖ Approved the Minutes of the ISRM Council Meeting 1993, the Report on the Activities of the Society (1993 July–1994 March), the Report on the Financial Situation of the Society (Running of 1993), and the Budget for 1995;
- ❖ Welcomed the reaffiliation of Poland;
- ❖ Selected by secret ballot the second Müller Award recipient, Dr. Neville Cook, Professor of Mining Engineering at the University of California;
- ❖ Approved an amendment to the ISRM Statutes and By-Law No. 2, permitting the ISRM President to be elected as a full voting member of the Board two years before the Congress at which her/his term would officially begin. [This change is intended to ensure a smooth, rapid and efficient transition between two effective Boards.];
- ❖ Selected EUROCK '96 on "Prediction and Performance in Rock Mechanics and Rock Engineering" in Turin, Italy, September 1996, as the ISRM International Symposium;
- ❖ Approved the publication of a fully revised Directory immediately after the Tokyo Congress. The next meetings of the Council will take place in Tokyo, Japan, 1995 September 24 and 26, in conjunction with the 8th ISRM International Congress.

ISRM BOARD 1995-1999

OFFICES OF ISRM PRESIDENT AND REGIONAL VICE-PRESIDENTS

Call for Nominations

As pointed out by the ISRM President at the Council Meeting in Santiago, the ISRM Board for the term 1995-1999 will be elected at the Council meeting, to be held on 1995 September 26, in Tokyo in conjunction with the 8th ISRM Congress.

National Groups are invited to nominate their candidates for office. In order to meet the stipulations of the ISRM Statutes and By-Laws, **these nominations must reach the ISRM Secretariat before 1995 March 26.**

Please do your best to help the Council have at least one candidate nominated for each office before the deadline.

National Group News

ISRM NG BELGIUM

New Board

The new Board of the Groupement Belge de Mécanique des Roches/Belgische Vereniging voor Rotsmechanica, (ISRM NG Belgium) for 1992-96, is: Chairman: Pedro Huergo; Vice Chairmen: Pierre Christiaens and Etienne Pohl; Secretary: Christian Schroeder. The address of the GBMR/BVRM is: Lab. de Géologie de l'Ingénieur, d'Hydrogéologie et de Prospection Géophysique, Univ. de Liège au Sart Tilman, Bétiment B 19, B-4000 Liège, Belgium; Tlp: 32 41 562216.

ISRM NG China

1994-1998 Board

The new ISRM NG China Board Members (also of the Chinese Society for Rock Mechanics and Engineering — CSRME) are: President, Prof. Sun Jun; Vice-President, Ha Quiling; Secretary (and Standing Vice President of CSRME), Zhang Qing.

Board members of the CSRME are Vice-Presidents: Wang Sijing, Liu Baoshen, Liu Tianquan, Liu Tongyou, Bai Shiwei, Song Yongjin, Xu Wenyao, Xie Liangying and Secretary: Fu Bingjun.

All correspondence for the ISRM NG China should be sent to Zhang Qing, Rock Mechanics Center, Dept. of Civil Engineering, Northern Jiaotong University, Beijing, 100044, P.R. China. Tlp: 324-0143, Fax: 225-5671.

Three Gorges Project

A special board of consultants, organized by CSRME reviewed and approved the design outline for the excavation and reinforcement of the high shiplock slopes (which have a maximum height of 170 m, cut into the left dam abutment of the Three Gorges Project) submitted by the Yangtze River Water Resources Commission of China, according to the agreement signed between the CSRME and the Chinese Yangtze Three Gorges Project Development Corporation (CYTGPDC).

Other consulting activity concerning the preliminary design document related to the excavation and reinforcement of the shiplocks slopes took place in September of this year.

The permanent shiplocks are one of the most important structures of the Three Gorges Project. They consist of a twin line, each with five continuous flights and an effective chamber size of 280 m x 34 m x 5 m.

CYTGPDC is a state-run enterprise, directly under the State Council of the P.R.C., and a legal economic entity. As the owner of the Three Gorges Project; the corporation is fully responsible for its construction, operation and management.

It is really a pioneering work for the CSRME, as a mass organization, to take responsibility for reviewing the official design documents.

ISRM NG IRAN

The Iranian Association of Geomechanical Engineering has been admitted as the ISRM NG IRAN. Prof. Farzan Rafia is the presiding officer and the number of members has increased to 15.

ISRM NG ITALY

Translation of ISRM Suggested Methods into Italian

The Associazione Geotecnica Italiana (AGI) (ISRM NG ITALY) is to be congratulated for having produced the Italian translation of the ISRM Suggested Methods for Rockbolt Testing (1974 March), and the ISRM Suggested Methods for Rock Anchorage Testing (1985 April). These were prepared by E. Cucchiarelli and P. Tommasi and have been published in the Rivista Italiana di Geotecnica, **XXVII** (1), 1993 Jan.-March, 51-69.

ISRM NG KOREA R

New Address

The new address of the Korean Rock Mechanics Society (KRMS) (ISRM NG KOREA R) is: Sam Lim Consultant Co., Jinro Mass Merchandising Center 15th Floor, Seocho-Dong 1445-15, Seocho-Ku, ROK-137-757 Seoul, Korea R; Tlp: 82-2-597-4767, 597-4768, Fax: 598-2148, or 598-2149.

ISRM NG POLAND

After several years of interruption, the Polish Society for Rock Mechanics was readmitted in the Society as the ISRM NG POLAND. The Board of this Group elected in 1993 for the term of office 1993-1997 is as follows: President: Prof. Jerzy Gustkiewicz; Vice-President: Prof. Alfred Bilinski; Vice-President: Ph.D. Anna Sieminska-Lewandowska; Secretary: M.Sc. Andrzej Nowakowski; Members: Prof. Miroslaw Chudek; Prof. Janina Pininska; Prof. Jan Walaszczyk; Prof. Waclaw Zuberek; Prof. Zdzislaw Zmudzinski, Ph.D. Leslaw Zabuski

ISRM NG SLOVENIA

Due to a computer problem, part of the Slovenian list of members was omitted from the Supplement to the 1992-93 Directory published in Vol. 2, No.1 of the ISRM *News Journal*. It is published in this issue:

Slovenian Geotechnical Society

Attn: Mr. Janko Logar; FAGG, Jamova 2, PO Box 579, 61001 Ljubljana. Tlp: 38-61-268-741; fax: 38-61-268-572; E-mail: janko.logar@uni-lj.si
President: Prof. Ivan Sovinc
Secretary: Mr. Janko Logar

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ZIGMAN, Franc, Dr., Ljubljana Mining Institute, Rudaerski Institut Ljubljana 61000 Slovenceva 93, Ljubljana

ISRM NG South Africa

The Executive Committee for 1994-1996 is: Chairman: Dr. J.N. van der Merwe; Vice Chairman: Dr. R.G. Gürtunca; Members: D. Bakker and W.J. de Maar.

In June the South African NG held a technical evening featuring two overseas speakers: Prof. E.T. Brown, Deputy Vice-Chancellor of Queensland University, Australia spoke on the topic of *Rock Engineering for Underground Excavations: Achievements and Challenges*. Dr. A. McGarr of the USA, gave a talk on *Some Questions of Current Interest Concerning the Causes, Mechanisms and Damaging Effects of Mining-Induced Earthquakes*.

ISRM NG Vietnam

The Vietnam National Society of Rock Mechanics invites members of the ISRM to attend its Tenth Anniversary Meeting in early 1995 in Hanoi. The Anniversary meeting will feature state-of-the-art papers on rock mechanics needs, projects and technology in Vietnam. Included will be discussions of major infrastructure projects requiring foreign rock mechanics expertise and investment.

Two days of technical presentations and small workshop group meetings will be followed by field visits to important rock mechanics projects sites. Hydro-power, tunneling and rock excavation projects will be visited.

National ISRM Societies and individual members can obtain more information about the meeting as follows:

Vietnam National Society of Rock Mechanics
Marshall Silver
United Nations Chief Technical Advisor
Nha Khach Thui Loi
166 Tran Quan Khai Street
Ha Noi, Vietnam
Tel: 84 4 245-485, Fax: 84 4 265-514

AWARDS

Dr. R. Kerry Rowe, an ISRM member through the Canadian Rock Mechanics Association/Association Canadienne de Mécanique des Roches (ISRM NG CANADA), was chosen as the recipient of the 1992 Shamsher Prakash Research Award.

FORTHCOMING EVENTS

1994 November 7-11, Bangkok THAILAND — Soil/ Ground Improvement Techniques, Course organized by the AGE. Fee: USD 500. Asian Geotechnical Engineering Info. Center (AGE), Asian Inst. of Technology, G.P.O. Box 2754, T-10501 Bangkok, Thailand. TLP: 66/2/5245862 or 516-2126 (fax); TLX: 84276.

1994 November 8-12, Caracas VENEZUELA — Venezuelan Experiences in Environmental Geotechnics, XIIIth Venezuelan Congress on Geotechnique, organized by the Sociedad Venezolana de Geotecnia (ISRM NG VENEZUELA). SVDG, Prof. Pietro de Marco Z., Colegio de Ingenieros de Venezuela - 3er Piso, Av. Principal Parque Los Caobos, Apartado Postal 4074, YV-1010 Caracas, Venezuela. TLP: 58 2 571-3824, 576-7947, or 215218(fax).

1994 November 14-18, Bangkok THAILAND — In-Situ Testing Techniques, Course organized by the AGE. Fee: USD 500. Asian Geotechnical Engineering Information Center (AGE), Asian Inst. of Technology, G.P.O. Box 2754, T-10501 Bangkok, Thailand. TLP: 66 2 524-5862 or 5162126 (fax); TLX: 84276.

1994 November 29-December 1, Turin ITALY — MIR '94, Fifth cycle of conferences on Rock Mechanics and Engineering, organized by the COREP and the Politecnico di Torino. Theme: Tunnelling in Difficult Conditions. Prof. G. Barla, Politecnico di Torino, Dip.to di Igegneria Strutturale, Corso Duca degli Abruzzi, 24, I-10129 Torino, ITALY. TLP: 39/11/5644824.

1994 November, Durban S AFRICA — 62nd ICOLD Executive Meeting and 18th ICOLD Congress.

1994 December 7–lO, Guangzhou (Canton) China — Internat'l Symposium on Anchoring and Grouting Techniques (ISAGT) Jointly organized by the Commission on Rock Anchorage and Grouting Techniques, Chinese Society for Rock Mechanics and Engineering, Academia Sinica, etc. Main theme: Application and development of rock and soil anchorage and grouting. Special lectures and discussions by experts and scholars on anchoring and grouting techniques used in world famous tunnels, dams and other underground works, Technical exhibition to display recent developments in anchoring and grouting materials, apparatus and techniques as well as in-situ and laboratory instrumentation: Prof. H.J. Xiong or Dr. Q.T. Wang, Secretariat ISAGT, c/o Guangzhou Chemical Grouting Co., Academia Sinica 81 Xianlie Rd,Guangzhou 510070, P.R.C. Tlp: 86-(020) 776-8512, Fax: 86-(020)-776-8677

1994 December 12-14, HONG KONG — COMSAGE, International Conference on Computational Methods in Structural and Geotechnical Engineering. Mr P.K.K. Lee, Conference Secretary COMSAGE, Dept of Civil & Structural Engng, The Univ. of Hong Kong, Pokfulam Road, Hong Kong, HONG KONG. TLP: 852 559-5337 (fax).

1994 or 1995, Sofia BULGARIA — 16th World Mining Congress, organized by the Internat'l Organizing Committee of the WMC. Mr Mieczyslaw Najberg, Ul. Krucza 36, PL-00921 Warszawa, Poland.

1995 February 14-16, New Orleans LA USA — Geoenvironment 2000. Dr Yalcin B. Acar, Civil Engineering Dept, Louisiana State Univ., Baton Rouge, LA 70803, USA. TLP: 1/504/388-8638 or 388-5990(fax).

1995 March 20-21, Brussels Belgium — Chalk and Shales, an ISRM-Sponsored Regional Symposium, organized by the groupement Belge de Mécanique des Roches/Belgische Vereniging voor Rotsmechanica (GBMR/BVRM) (ISRM NG Belgium). Geological properties of shale and chalk ; Experimental determination of the mechanical parameters; Rheological behaviour: plastic deformation, constant and cyclic loading; viscosity, anisotropy, port-mechanics, unsaturated materials, effect of capillary forces, thermal effects, physicochemical coupling; fracture mechanics, localization of the deformation and fracturing, joints, damage theories, micro-mechanics, effect of textures, and scale effects; Aspects related to the environment: slope stability and waste disposal; Design of excavations, predicted and observed behavior: a. surface structures; fills, excavations, reinforcements; b. underground openings; c. foundations; d. boreholes. L: Dutch, English, French and German. TS: Papers 1994 12 31. Fee: BEF 12.000; BEF 8.000 for students and researchers. Colloquium Chalk and Shales, Mr B. Froment, Fac. Polytechnique de Mons (FPMs), Lab Forages Profonds et Mécanique des Roches, Rue du Joncquois, 53, B-7000 Mons, Belgium. Tlp: 32 2 650-2737 (ULB) or Fax: 65 374600 (FPMs).

1995 March 21-23, Nashville TN USA— Geosynthetics '95. Industrial Fabrics Assoc. International (IFAI), 345 Cedar St., Suite 800, St Paul, MN 55101, USA. TLP: 1/612/222-2508 or 222-8215 (fax).

1995 April 2-7, St Louis MO USA — 3rd Internat'l Conference on Recent Advances in the Geotechnical Earthquake Engineering and Soil Dynamics. Themes: 1. Static and dynamic engineering soil parameters, and constitutive relations of soils; 2. Model testing in a cycling loading; 3. Liquefaction and ground failure; 4. Dynamic earth pressures, and seismic design of earth retaining structures; 5. Soil structure interaction under a dynamic loading; 6. Stability of slopes and earth dams under earthquakes; 7. Soil amplification during an earthquake, and microzonation; 8. Seismology: predicting a strong ground motion for the design; 9. Geotechnical analysis of recent earthquakes; 10. Wave propagation in soils; 11. Engineering vibrations and solutions; 12. Machine foundations and model tests; 13. "Engineering aspects of the Central United States Earthquake Region". Prof. Shamsher Prakash, Conference Chairman, Dept of Civil Engineering, Univ. of Missouri- Rolla, Butler-Carlton Civil Engineering Hall, Rolla, MO 65401-0249, USA. TLP: 1 314 341-4461, 341-4489, or 341-4729(fax).

1995 April 3-7, Johannesburg S AFRICA — Centennial Geocongress '95. The Congress Secretariat, Centennial Geocongress, P.O. Box 36815, ZA-0102 Menlo Park, S AFRICA. TLP: 27 12 473398(also fax).

1995 April 8, Vienna AUSTRIA — Dynamics of Fractured Rocks, a workshop, with a special emphasis on the mining in jointed and faulted rocks, held in conjunction with the MJFR-2 conference (April 10-14). L: English. Doz.-Dr H.P. Rossmanith, Inst. of Mechanics, Technical Univ. Vienna, Wiedner Hauptstr. 8- 10/325, A-1040 Vienna, AUSTRIA. TLP: 43/1/58801-5514, or 5875863(fax).

1995 April 10-14, Vienna AUSTRIA — MJFR-2, the 2nd international conference on Mechanics of Jointed and Faulted Rocks, organized by the Inst. of Mechanics, Technical Univ. Vienna, Vienna AUSTRIA, the Austrian Society of Geomechanics (ôGG) (ISRM NG AUSTRIA), and the International Working Group on Tectono-Mechanics (IWTM). Theme: Science in the Service of Engineering. Topics: Geology (structural geology; mechanics of the formation of faults and joints; physical and mechanical properties of jointed rocks; constitutive modelling of jointed rocks, difficult rocks, and difficult rock conditions); Faulting (mechanics of the tectonic faulting; shear rupture; time-dependent deformation; special problems); Applied Fracture Mechanics (fracture and damage processes; failure criteria in jointed rocks; rock fragmentation; formation and control of fracturing around highly stressed openings in rocks; fracture anisotropy in rocks; support of fractured and weak rocks; mechanics and physics of rock interfaces); Dynamics of Jointed Rocks (dynamic fracture and fracture propagation; wave propagation in jointed and heavily damaged rock masses; non-local effects; dynamic fatigue; dynamics of discontinuities; discrete element modelling; modelling of the dynamic fracturing of rocks; rock bursting); Physical Modelling (photomechanics techniques; new laboratory techniques); Numerical Studies (numerical modelling and simulation; applied numerical modelling; dynamic simulation studies; numerical techniques; computer graphics aided techniques, applied to jointed and faulted rock masses; numerical simulation for the geotechnical stability; model verification); Seismicity and Tectonics (crustal tectonics; seismic attenuation; fractoemission; prediction of the mechanical behaviour of large, highly stressed fractured rock masses; tectono-fractography); Testing (characterization of jointed rock masses; failure characteristics; shear testing; filled joints and interfaces; acoustic emission; in-situ testing results and interpretations; large scale testing; field testing for the nuclear and toxic waste; fracture toughness assessment; core drilling and evaluation; pre- and post-failure behaviour of rock samples); Instrumentation (stress measurement in fractured rocks; control and monitoring of the mechanical behaviour of jointed and faulted rocks; large scale instrumentation); Hydraulics (hydromechanics of jointed rock masses; permeability, and heat and fluid flow; assessment of transport properties of rocks; geothermal fracturing; hydrocarbon reservoirs and the oil exploration; grouting of jointed rocks; fluids and the hydrodynamic modelling in fractured rocks; fluid-fractures-in-situ stress interactions); Mining and Quarrying (mining in jointed and faulted rock formations; seismic and mining induced fractures; fault stability in mines; ground support and rock mass failure; rock burst and seismicity in mines; mining-induced subsidence; pillar stability; strata mechanics; rock caving); Tunnelling and Underground Construction (excavating and underground construction in difficult rocks; stability problems; rock caverns; problems with dams and hydroelectric plants located in a difficult rock terrain); Environmental Technology (tunnelling and rock mechanics for the storage; nuclear and toxic waste repositories; assessment of the safety; acceptability and environmental compatibility; stability of rock blocks; waste dumps and slopes; engineering structures built in fractured rocks); Special Problems (special geological regions (Rand, Alps, Rift, Rockies, ...); learning from failures; case studies). L: English. TS: Papers - 19941130. An exhibition of scientific equipment and text-books will be staged. A social programme shall be arranged. Doz.-Dr H.P. Rossmanith, Inst. of Mechanics, Technical Univ. Vienna, Wiedner Hauptstr. 8- 10/325, A-1040 Vienna, AUSTRIA. TLP: 43/1/58801-5514, or 5875863(fax).

1995 May 6-11, Stuttgart GERMANY — 21st ITA Annual Meeting, to be held in conjunction with the World-Tunnel Congress and Stuva-Tagung '95. Mr Claude Berenguier, ITA/AITES Secretariat, 109, Av. Salvador Allende, F-69500 Bron, FRANCE. TLP: 33/78/260455 or 264039(fax); TLX: 370008 CETELYON.

1995 May 8-11, Stuttgart GERMANY — World-Tunnel Congress and Stuva-Tagung '95, celebrating the 35th anniversary of the STUVA (ITA NG GERMANY), sponsored by the ITA. STUVA - Studiengesellschaft fÅr Unterirdische Verkehrsanlagen e.V., Mathias-BrÅggen-Str. 41, D-5000 Kîln 30, GERMANY. TLP: 49 221 597-950 or 597-9550(fax).

1995 May 17-19, Sherbrooke PQ CANADA — 4th International Symposium on Pressuremeter and Dilatometer Testing, sponsored by the ISSMFE, the Canadian Geotechnical Society, and the Centre de Recherche Interuniversitaire sur le Béton (CRIB). Topics: Technological and theoretical developments; Laboratory and field testing; Applications in the geotechnical and structural design, for cohesive and granular soils, permafrost, rock, and concrete. L: English, French. Prof. Gérard Ballivy, Dép.t de Génie Civil, Univ. de Sherbrooke, Sherbrooke, PQ J1K 2R1, CANADA. TLP: 1/819/8217115 or 8217974(fax).

1995 May 23-27, Belgorod RUSSIA — 3rd International Symposium on Exploitation of Mineral Resource Deposits, and Underground Construction in Complicated Hydrogeological Conditions. All-Russian Scientific and Research Inst., VIOGEM - B. Khmelnitsky St., 86, SU-308007 Belgorod, RUSSIA. TLP: 60523 or 61756.

1995 May 24-26, Crete GREECE — SDEE 95, Conference on Soil Dynamics & Earthquake Engineering. Mrs Susi King, Wessex Inst. of Technology, Ashurst Lodge, Ashurst, Southampton SO4 2AA, UK. TLP: 44/703/293223 or 292853(fax).

1995 May 28-June 1, Copenhagen DENMARK — XIth ISSMFE European Conf. on Soil Mechanics and Foundation Engineering, spons. by the IAEG, and org. by the Danish Geotechnical Society (ISSMFE MS DENMARK). Theme: The Interplay between Geotechnical Eng. and Engineering Geology. Dr Jurgen S. Steenfelt, c/o ICS Internat'l Conference Services, P.O. Box 41, Strandvejen 171, DK-2900 Hellerup, Denmark. TLP: 45/31/ 612195 or 612068(fax). Danish Geotechnical Society, Maglebjergvej 1, P.O. Box 119, DK-2800 Lyngby, Denmark. TLP: 45/42/884444 or 881240 (fax).

1995 August 29-September 2, Beijing CHINA — 10th ISSMFE Asian Regional Conference on Soil Mechanics and Foundation Engineering. Topics: Soil properties; Regional soils and their engineering behaviour; Deep and shallow foundations; Earth structures and underground geotechnics; Ground improvement techniques; Natural hazard and environmental geotechnics. L: English. Prof. Can Wen Yang, Secretary General of the Conference, China Academy of Railway Sciences, Geotechnical Div., TJ-100081 Beijing, CHINA PR. TLP: 86/1/3249435 or 8329195(fax).

1995 September 25-29, Makuhari (Chiba) JAPAN — ISRM 8th Internat'l Congress on Rock Mechanics, organized by The Japanese Committee for the ISRM (ISRM NG JAPAN). Keynote: Frontiers of Rock Mechanics towards the 21st Century. Themes: 1. Geology, Site Exploration, and Testing (Subsurface mapping, geotomography, and remote sensing; Exploration of joints, micro- and macro-structures; In situ measurement of stress, physical and chemical properties; Earthquakes, volcanic activities, and tectonics; Advances in geomechanics and geophysics; etc.); 2. Physical Properties and Modelling of Rocks (Properties of joints and jointed rocks; Scale effect; Modelling of discontinuous media, and case studies; Fracture mechanics, rheology, and dynamic behaviour; Effect of the pore pressure; Rocks at great depth; etc.); 3. Near Surface Excavations, Stability of Slopes, and Foundations (Borderline problems between soil mechanics and rock mechanics; Design and construction on weak rocks, swelling rocks, and tectonically disturbed rocks; Improvement of properties of rocks; Urban, waterfront, and offshore development; Foundations of dams, bridges, and power stations, etc.; Landslides, earthquake engineering; etc.); 4. Excavation and Stability of Underground Openings (Design and construction of tunnels and large caverns; Tunnel boring machines, blasting, and cutting; Tunnel excavation in difficult conditions; Deep boring; Storage of fuel, etc. in rock caverns; New and extensive utilization of underground openings; Long-term and seismic stability of large caverns; Maintenance of underground structures; etc.); 5. Heat, Water Flow, and Chemical Transport in Rock Masses (Modelling and control of the groundwater flow; Modelling of the oil and gas flow; Hot dry rocks and geothermal development; Nuclear and industrial waste disposal; Fluid-rock interaction and grouting; Thermal and fluid fracturing; Global environmental effect; etc.); 6. Information Systems and New Technology in Rock Mechanics (Artificial intelligence and expert systems; Smart excavation system and control system; Monitoring and data analysis by computer; Method and case studies of safety evaluation and prediction; etc.). L: English, French, German; Japanese (only for oral presentations) (simul. transl.). TS: Bulletin No. 2 : 1994 November; Papers: 1995 January. Poster sessions September 26 & 28. On September 27, 4–8 workshops on specialized themes. Technical exhibition, including displays of new technologies, data analysis, and publications relating to machinery, measuring instruments, computer manufacturers, and publishers, is being prepared. Two full-day technical excursions to the Tokyo Bay Highway tunnel (length, 9 km; diameter, 14 m) and to a Tokyo Metropolitan Subway tunnel (diameter, 9 m; depth, 20 m). Social and accompanying persons program. Two 2-3-day pre-Congress and three 4-5-day post-Congress tours, visiting the Seikan tunnel, the Honshu-Shikoku bridge system, underground power stations, nuclear power plants, large dams, geothermal fields, mines, volcanoes, active faults, and tourist attractions, are being arranged. Fee: JPY 50.000; JPY 20.000 for students; JPY 25.000 for accompanying persons. The 1995 ISRM Board, Council, and Commission Meetings will be held on September 23-24 and 26, in conjunction with this Congress. Secretariat for the 8th International Congress on Rock Mechanics, c/o Conference and Event Dept, Simul International, Inc., Kowa Bldg No. 9, 1-8-10, Akasaka, Minato-Ku, J-107 Tokyo, JAPAN. TLP: 81/3/358-68691 or 358-64531(fax).

1995 October 1-4, Anaheim CA USA — Society of Petroleum Engineers Annual Technical Conference and Exhibition.

1995 October 16-20, The Hague, The Netherlands — 5th Internat'l Symposium on Land Subsidence. Themes: causes, measuring and effects of land subsidence,.Secretariat FISOLS 95, Mr. F.H. Schröder, c/o Netherlands Geodetic Commission, P.O. Box 5030, NL-2600 GA Delft, The Netherlands. Tlp: 31 15 782819, Fax: 31 15 782745, e-mail schroder@tudgv1.tudelft.nl

1995 November 14-16, Tokyo JAPAN — IS-Tokyo, the 1st International Conference on Earthquake Geotechnical Engineering. Topics: Laboratory and in-situ tests on the dynamic behaviour of soils, including model tests; Case histories of recent earthquakes, with an emphasis on the dynamic response of grounds, liquefaction problems, and ground failure. L: English. Dr Ikuo Towhata, Secretary of the IS-Tokyo, Dept of Civil Eng., Univ. of Tokyo, 7-3-1, Hongo, Bunkyo, J-113 Tokyo, Japan. TLP: 81/3/38122111 Ext. 6121, or 38185692(fax).

1995 December 11-15, Cairo EGYPT — XIth ISSMFE African Regional Conference on Soil Mechanics and Foundation Engineering. 1995 ISSMFE Board and Council Meetings will be held immediately before this Conference. Prof. M.K. El Ghamrawy, General Sec., The Egyptian Geotechnical Society, P.O. Box 23, ET-12311 Dokki, EGYPT. TLP: 20/2/3468648 or 3440940 (fax).

1995, Guadalajara MEXICO — Xth ISSMFE Panamerican Regional Conference on Soil Mechanics and Foundation Engineering.

1995, Jerusalem ISRAEL — Engineering Geology in Desert Environments: Rock/Water Interaction, IAEG-sponsored International Symposium on Engineering Geology in a Desert Environment, Rock Water Interaction, P.O. Box 50006, IL-61500 Tel Aviv, ISRAEL. TLP: 972 3 655 674 (fax); TLX: 341171 KENS.

1996 June 17-21, Trondheim NORWAY — 7th International Symposium on Landslides, sponsored by the ISSMFE and the IAEG. ISL'96, SEVU, Congress Dept, The Norwegian Inst. of Technology, N-7034 Trondheim, Norway. TLP: 47 7 3595247 or 359-5150 (fax). Norwegian Geotechnical Society, P.O. Box 40, Taasen, N-0801 Oslo 8, Norway.

1996 July 1-7, Adelaide SA AUSTRALIA — 7th Australia and New Zealand Geomechanics Conference, sponsored by the IAEG.

1996 August, Beijing CHINA — 30th International Geological Congress, hosted by the Geological Society of China, & sponsored by the IAEG. Secretariat Bureau, 30th International Geological Congress, P.O. Box 823, TJ-100037 Beijing, CHINA PR.

1996 September 2-5, Turin ITALY — Prediction and Performance in Rock Mechanics and Rock Engineering, an internat'l symposium, organized by the Associazione Geotecnica Italiana (AGI—ISRM NG ITALY). Technical Sessions: I. Fundamental topics in rock mechanics and rock engineering; II. Foundations and slopes; III. Tunnels and underground openings; IV. Environmental engineering; V. Rock engineering in the context of historical monuments and sites. Workshops: 1. Rock mass modelling: continuum versus discontinuum; 2. Natural slopes instabilities and civil protection implications; 3. Tunnelling in difficult rock conditions; 4. Stability conditions of a single opening, in a rock mass at depth. Topics: Fundamental Aspects of the Rock Characterization (Rock, joint, and rock mass properties and behaviour; Rock mass characterization; Coupled mechanical and hydrogeological processes; Recent developments in modelling techniques; Recent advances in the monitoring); Use of Analytical and Computational Methods for Predictive Purposes; Case Histories Which Compare the Predicted and Observed Behaviour of Rock Engineering Projects, Such As Foundations of Dams, Bridges, and Large Structures, Natural and Excavated Slopes, Tunnels and Caverns, Mining Structures, Environmental Engineering (including radioactive waste repositories, etc.), and Engineering Problems Associated with Historical Monuments and Sites (Rock mechanics program for the rock engineering characterization; Geotechnical model formulation (conceptualization of site characterization data); Design analyses performed (analytical and computational schemes); Identification of quantities to be monitored, and monitoring program adopted; Changes and improvement of the design during the construction, as a consequence of the monitoring; Quantitative evaluation of the reliability of performance predictions, compared with the observed behaviour). L: English, French, German (simul. transl.). Poster sessions. Technical exhibition of equipment for in situ work investigations and laboratory studies. 3 full-day technical visits, to a 15 km long hydro-tunnel, an ancient landslide, and a highway/railway tunnel. Post-symposium tours, to ongoing works.

1996 October 6-9, Denver CO USA.— Society of Petroleum Engineers Annual Technical Conference and Exhibition.

1996, Summer, Montréal — 2nd N American Rock Mechanics Symposium (NARMS), sponsored jointly by the Canadian Rock Mechanics Association (CARMA—the ISRM NG CANADA), the Sociedad Mexicana de Mecanica de Rocas (SMMR—ISRM NG MEXICO), and the U.S. Nat'l Committee on Rock Mechanics (USNC/RM—ISRM NG USA)

Corporate Members

All Corporate Members of the ISRM are listed in every issue of the *News Journal,* under a number of 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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LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL (LNEC) Lisboa, Portugal
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ISMES–INSTITUTO SPERIMENTALE MODELLI E STRUTTURE Bergamo, Italy
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SNOWY MOUNTAINS ENG. CORPORATION Cooma North, Australia
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C—CONSULTANTS

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HOKKAIDO ENGINEERING CONSULTANT CO. LTD Hokkaido, Japan
HOKUDEN SANGYO CO. LTD Toyama, Japan
HOKUDEN KOGYO CO. INC. Hokkaido, Japan
IDOWR ENGINEERING CO. LTD. Tokyo, Japan
I.N.A. CO. LTD Tokyo, Japan
INGENIEUR-GEOLOGISCHES INSTITUT Westheim, Germany
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President — *continued from page 2*

All of these impressive developments notwithstanding, the central problem of defining the strength and deformability of a rock mass clearly remains a primary issue for rock engineering. Dr. Evert Hoek, a keynote speaker at the Symposium, commented on how surprised he and Professor E.T. Brown were to find so little practically useful information on rock mass strength when preparing the book "Underground Excavations in Rock." The Hoek-Brown criterion was developed as a first attempt to fill the void. However, as he outlines in his letter to the Editor on page 23 of this issue, the criterion was not intended to be applied as universally as it seems to be. Dr. Hoek's comments provided the stimulus for the main theme of this issue, to which he and Prof. Sakurai have generously contributed.

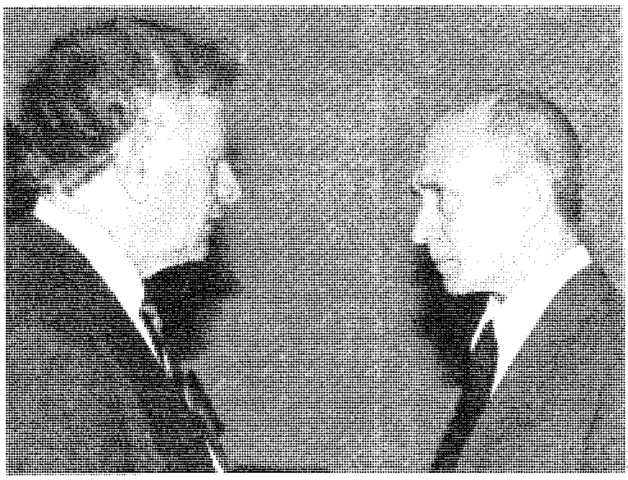
Rocha Medal/Schlumberger Lecture

Additional highlights of the 1994 International Symposium were the presentation of the 1994 Manuel Rocha medal to Dr. Shinichi Akutagawa of Japan, for his Ph.D. thesis, "A Back Analysis Program System for Geomechanics Applications," supervised jointly by Professors E.T. Brown and G. Beer of the University of Queensland and the 1994 Schlumberger Lecture given by Dr. Alexander M. Linkov, Russia. Dr. Linkov summarized his research on "Dynamic Phenomena in Mines and the Problem of Stability." (Copies of Dr. Linkov's extended notes on this topic are available from the ISRM Secretariat; see page 48).

Council Meeting

Several important decisions were made by the ISRM Council at its meeting on May 9. The most significant was the approval by Council of the

Dr. Shinichi Akutagawa receives the 1994 Rocha medal from ISRM President C. Fairhurst, during the ISRM International Symposium & ExpoMin, in Santiago, Chile. Session chairman Dr. Luis Valenzuela, former President of the Chilean Society for Geomechanics (SOCHIGE), and currently Vice-President for South America of the International Society for Soil Mechanics and Foundation Engineering (ISSMFE), is in the background.

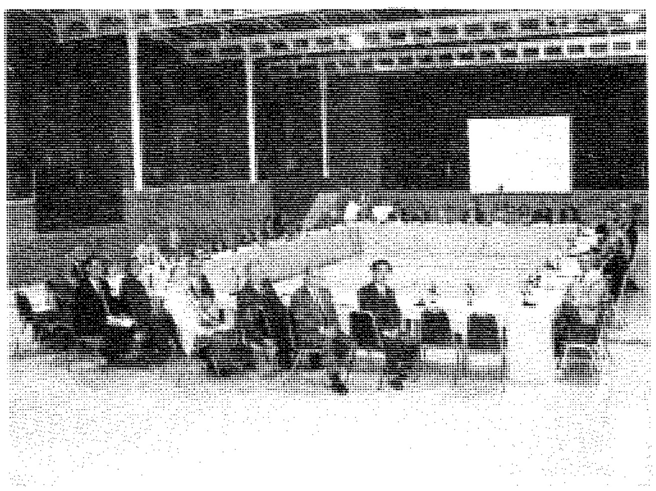


Dr. Alexander Linkov, 1994 Schlumberger Lecturer, with Charles Fairhurst.

Board's recommendation to change the procedure for election of ISRM President. Under the new procedure, election of the President will take place two years before the Congress at which her/his term would officially begin. During the two years, the "President-elect" would become a full (voting) member of the ISRM Board.

The intent of the change is to enable the President-elect to become familiar with important issues for the Society and the reasons for the policies and actions of the Board, thereby facilitating an efficient transition and improving continuity between successive Boards. The new procedure will take effect at the 1997 ISRM International Symposium, i.e., two years before the Ninth ISRM Congress to be held in Paris.

Council members also voted to select Professor Neville G.W. Cook, University of California at Berkeley, USA, to receive the second Müller Award. The Award is made once every four years at the ISRM Congress in recognition of distinguished contributions to the profession of rock mechanics and rock engineering. Six nominations of exceptional leaders were received—two from Asia; two from Europe; one from North America; one from South America.



ISRM Council Members, during May 9 meeting.

Session participants at the ISRM International Symposium in Santiago.

Dr. C. Derek Martin (Canada) was selected to receive the 1995 Rocha Medal, for his Ph.D. Thesis "The Strength of Massive Lac du Bonnet Granite Around Underground Openings." Dr. Martin was advised by Prof. B. Stimpson, Univ. of Manitoba.

Eurock '96, to be held in Turin, Italy, September 2-5, was designated as the site for the 1996 ISRM International Symposium.

Further details of the Council meeting are presented in the Council Minutes, copies of which have been distributed to each National Group.

Visit to India

An invitation to present a week-long Workshop on Numerical Modelling in Rock Mechanics Design, with Dr. Biswas Dasgupta of the National Institute for Rock Mechanics, Kolar Gold Fields, followed by a week of visits, discussions and lectures to various geological and geotechnical groups and hydro-power projects, provided considerable insight into the remarkable opportunities and challenges for rock mechanics and rock engineering in India.

The visit was arranged by the Central Soil and Materials Research Station (CSMRS), New Delhi, by Dr. V.M. Sharma, CSMRS Director and Dr. A.K. Dhawan, Research Director, both of whom attended the Workshop, accompanied me on the visits and were most hospitable. I am most grateful for their efforts in making the visit so informative and rewarding.

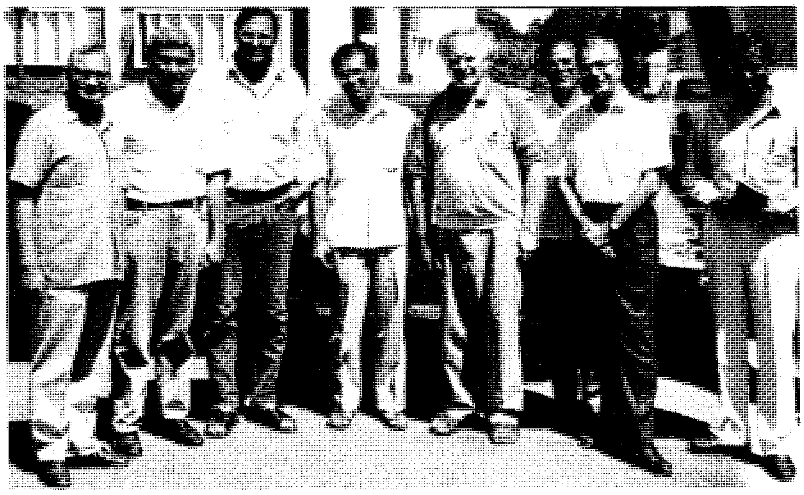
The development of hydro-power facilities in the seismo-tectonically active Himalayas are well underway, with additional projects contemplated over the next fifty or more years. There are major additional needs for the development of the national physical infrastructure, expansion and upgrading of underground facilities for water supply and sanitary systems in large cities, and other less traditional uses of underground space to alleviate urban problems.

Further discussion of these and other developments is presented in the article "Rock Mechanics Developments in India," by Dr. V.M. Sharma and Dr. A.K. Dhawan in the *Int. Jour. Rock Mech. Min. Sci.* **31** (1) Feb. 1994—Indian Rock Mechanics.

Indian scientists and engineers are responding vigorously to these challenges. The recently formed Indian Society for Rock Mechanics and Tunnelling Technology (ISRM/TT) already has approximately 1,000 members and is likely to grow further. The Society publishes a quarterly Newsletter, and will soon publish the first issue of its own Journal. The Chief Editor, Prof. Bhawani Singh of the University of Roorkee has established an International Editorial Advisory Board to ensure that the Journal maintains the highest standards. Discussions with Indian leaders in applied rock mechanics and related topics and the contagious enthusiasm of ISRM/TT members convinced me that significant contributions can be expected in the future from our Indian colleagues.

Dr. Bhawani Singh and his colleagues at the University of Roorkee are well aware of the need for improved understanding of the deformability and strength of rock masses, especially for projects in the Himalayas, and have already made impressive progress. Some results have been published, with more to come. Thus, the trip to India reinforced the message brought back from Santiago. More work on rock mass behaviour is needed. This is, of course, not a new discovery. As

Left to right: Mr. H.C. Verma, President, Indian Geotechnical Society; Charles Fairhurst; Mr. H.C. Bharadvaj, Chairman & Managing Director, Nathpa Jhakri Power Corporation, President, Indian Society for Rock Mechanics and Tunnelling Technology (ISRM/TT); Mr. D.G. Kadkade, Technical Director, Jaiprakash Industries; Mr. B. Uppal, Vice-President, Indian Road Congress; Dr. M.A. Chitale, Secretary-General, International Commission on Irrigation and Drainage, Former Secretary, Ministry of Water Resources; Dr. V.M. Sharma, Director, Central Soil and Material Research Station (CSMRS); Mr. Goel, Superintending Engineer, Nathpa Jhakri, Power Corporation; Dr. A.K. Dhawan, Chief Research Officer, CSMRS, and Vice-President ISRM/TT.



Shown left to right, outside the civil engineering building at the University of Roorkee, are: Dr. A.K. Dube, Dr. A.K. Dhawan, Dr. V.M. Sharma, Prof. Bhawani Singh, Charles Fairhurst, Dr. U.N. Sinha, Dr. Subhash Mitra and Dr. V.K. Mehrotra.

I have noted before, this need was a primary motivation for Dr. Müller in his drive to establish the ISRM in 1962, and there have been many discussions and international conferences on Scale Effects in Rock Masses—most recently at Eurock '93 in Lisbon. The Society has had a Commission on Scale Effects in Rock Mechanics since 1988, Dr. A.P. Cunha, President. Even so, there has been little or no improvement, in practice, over the Hoek-Brown criterion which, as one of its originators asserts in this issue, was intended as a point of departure, a basis for further improvement—and not a final solution to the problem.

Back analysis—by which field scale deformability and sometimes strength, can be inferred from in-situ measurement, is a potentially valuable approach to the development of additional data. Professor Sakurai is an international leader in the application of back analysis. I am most grateful to both Drs. Hoek and Sakurai for providing their articles for this issue, and hope that they will stimulate the needed international attention to this important problem.

As part of their work on the Commission on Education, Drs. Windsor and Thompson have prepared a valuable report illustrating the potential of multi-media in rock mechanics education and training. Their efforts to prepare this extract from the full report are sincerely appreciated. We look forward to reactions from readers on all of the articles, and any other topics that you consider worthy of comment and discussion.

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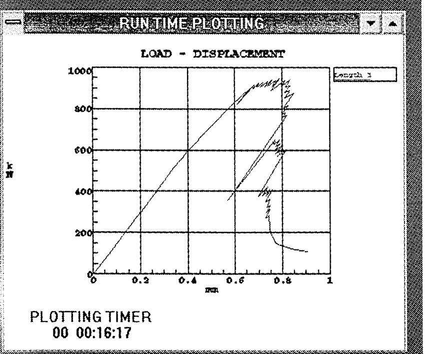

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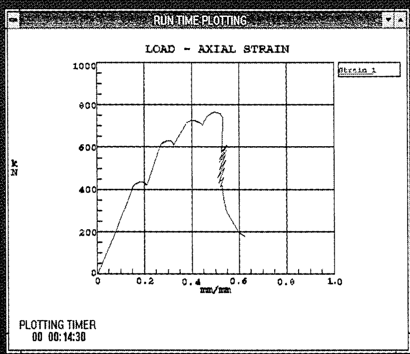

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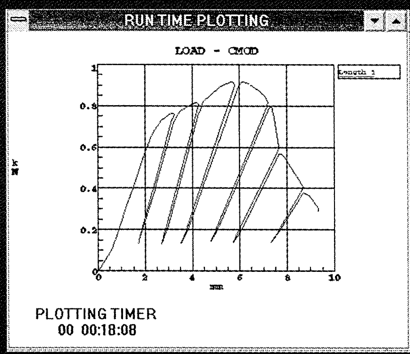

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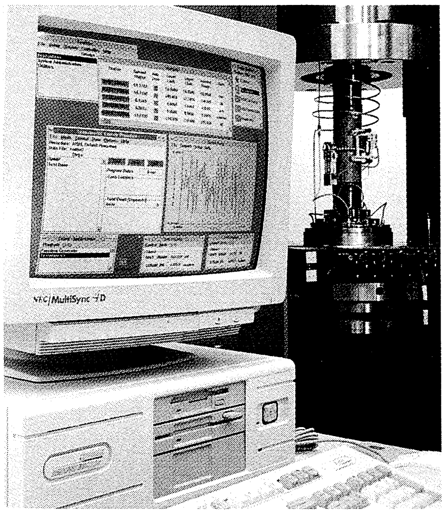

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FLAC

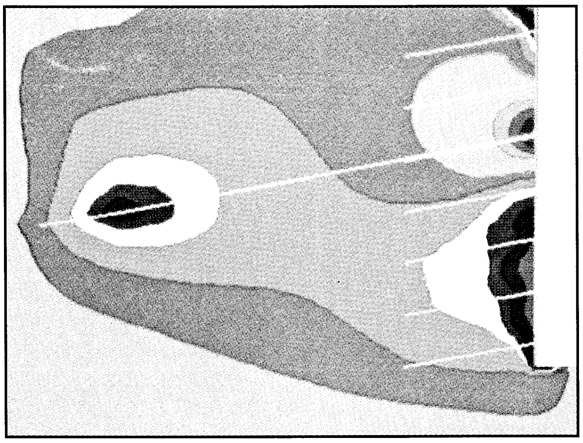
有限差分法地盤大ひずみ塑性解析プログラム

The internationally popular *FLAC* (***F**ast **L**agrangian **A**nalysis of **C**ontinua*) is a two-dimensional continuum code developed by Dr. Peter Cundall. *FLAC* is designed for use on personal computers or workstations and is well suited to the modelling of small- or large-strain, nonlinear, dynamic or static geomechanical problems. A sequence of model states may be captured and displayed graphically as a "movie" to aid in the understanding of the model behaviour. *FLAC*^{3D}, a new three-dimensional continuum code from Itasca, is also available.

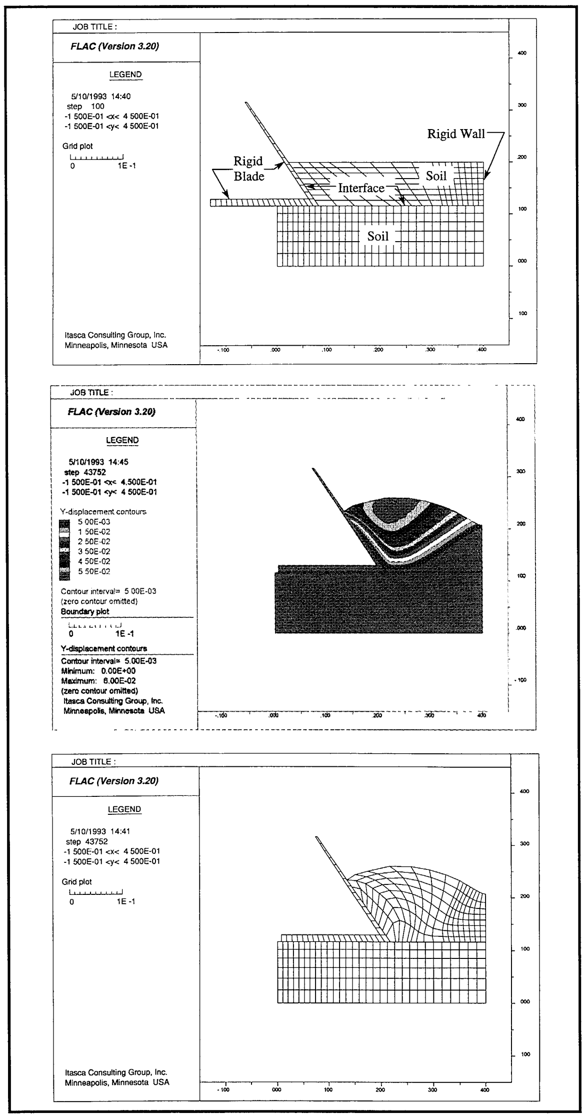
Features

- ❒ User-defined constitutive models
- ❒ Modified Cam-Clay constitutive model
- ❒ Isotropic and anisotropic elasticity
- ❒ Elasto-plasticity (Mohr-Coulomb yield criterion, with or without tension, non-associated flow rule)
- ❒ Ubiquitous joint (slip-plane plasticity)
- ❒ General strain-softening/hardening model
- ❒ Pore pressure; effective stress analysis
- ❒ Coupled mechanical-fluid flow analysis
- ❒ Large- or small-strain modes
- ❒ Plane-strain, plane-stress or axisymmetric modes
- ❒ Static or fully dynamic analysis
- ❒ Sliding and opening interfaces
- ❒ Structural elements
- ❒ Built-in programming language (*FISH*) to add user-defined functions, variables and constitutive models
- ❒ Every element may have a different model or property; a continuous gradient in properties may be specified

ＦＬＡＣは個別要素法コードＵＤＥＣ，３ＤＥＣを発表したＤｒ．Ｐ．Ｃｕｎｄａｌｌが同様の有限差分ロジックを用いて連続体の塑性大変形を解析するために開発したコードで、現在、全世界で数多く使用されています。
有限差分法は、地盤・岩盤を有限な領域内で離散化し、運動方程式と構成則を差分方程式として解析するもので、有限要素法に比べ非線形大歪が扱えることで大きな優位性を持っています。
ＦＬＡＣは小－大歪，非線形，動的－静的挙動を始めとし、豊富な機能・オプションを備えたＰＣ，ワークステーション用の２次元解析コードです。また、現在３次元版ＦＬＡＣの開発が進められております。



Nailed wall with tieback: VGA screen output.



Simulation of blade ploughing through frictional, non-cohesive material. — *Courtesy Mitsubishi Heavy Industry*

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◆ *FLAC* is available in executable code for 80386/486, Pentium PCs and for SUN SPARCstations.
◆ *FLAC* is owned by Itasca Consulting Group, Inc. and marketed under licence in Japan by CRC Research Institute, Inc.