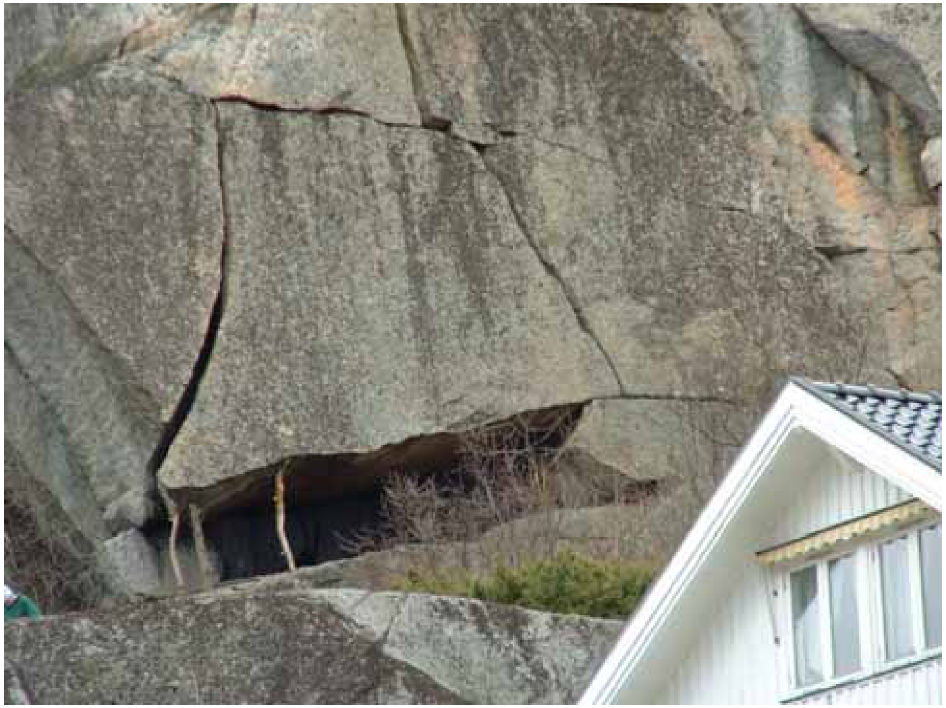
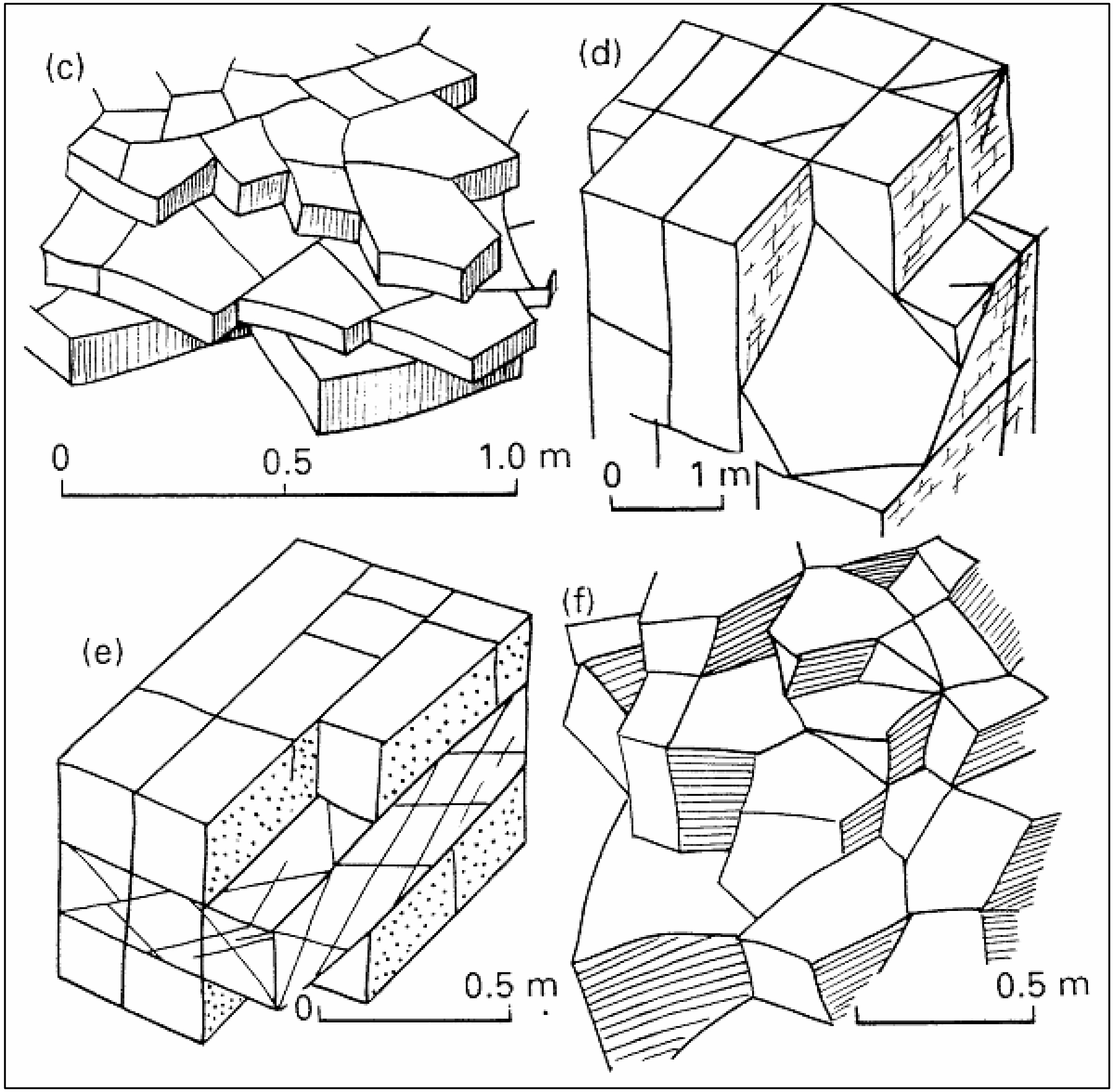
1. INTRODUCTION TO SOME TOPICS IN ROCK ENGINEERING



CONTENT

- SOME OF THE USES OF ROCK MASS CHARACTERIZATION
- MODELLING ROCK FAILURE - SOME PROBLEMS AND SOLUTIONS
- ROCK MASS DEFORMATION MODES DUE TO JOINT BEHAVIOUR
- SOME OF THE TECHNIQUES FOR JOINT CHARACTERIZATION AND SHEAR STRENGTH ESTIMATION

VARIABILITY OF STRUCTURE…..IN EACH ROCK TYPE



VARIABILITY of STRUCTURE…FROM METER TO METER

VARIABILITY…..FROM PLACE ***TO PLACE***

Q = 1000 (or better)

Q = 100/0.5 x 4/0.75 x 1/1

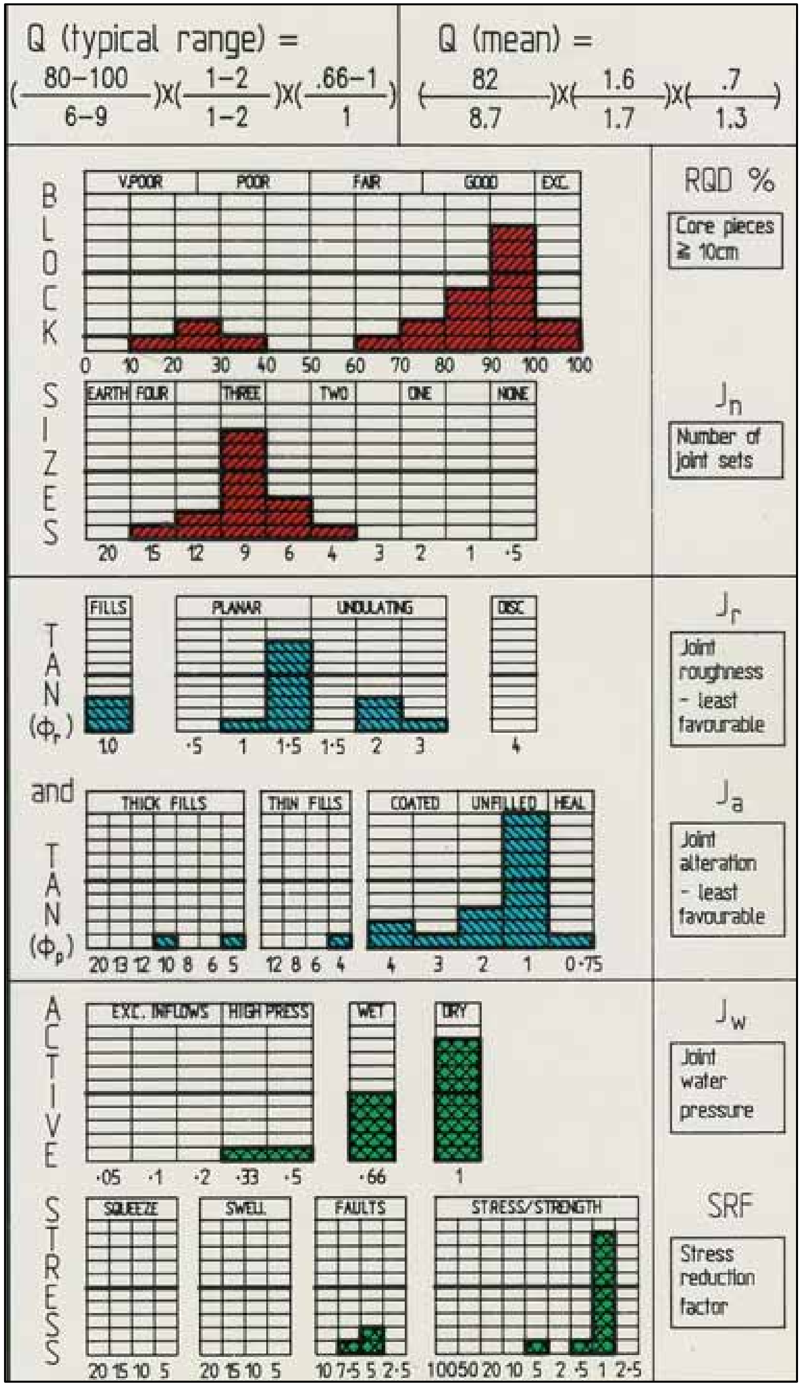
Q = 0.001 (or worse)

Q = 10/20 x 1/8 x 0.5/ 20

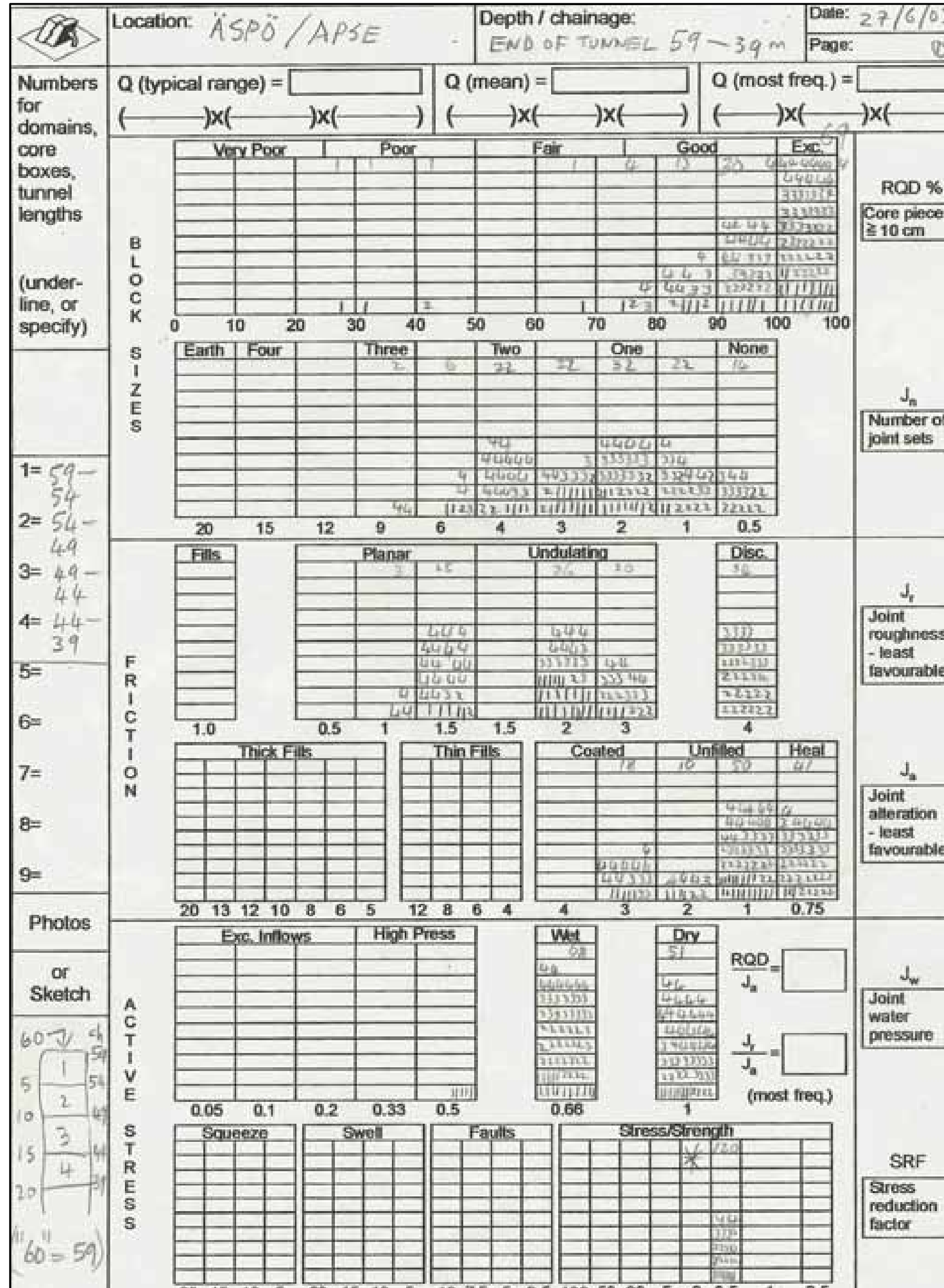
WITH THIS INTRODUCTION IT IS NO SURPRISE THAT WE USE CHARACTERIZATION METHODS

- to capture the structure
- to capture the joint properties
- to capture the strength
- to capture the stress
- to capture the water

All of the above in an approximate way…but useful to engineers…who need a solution…..but who cannot model everything !

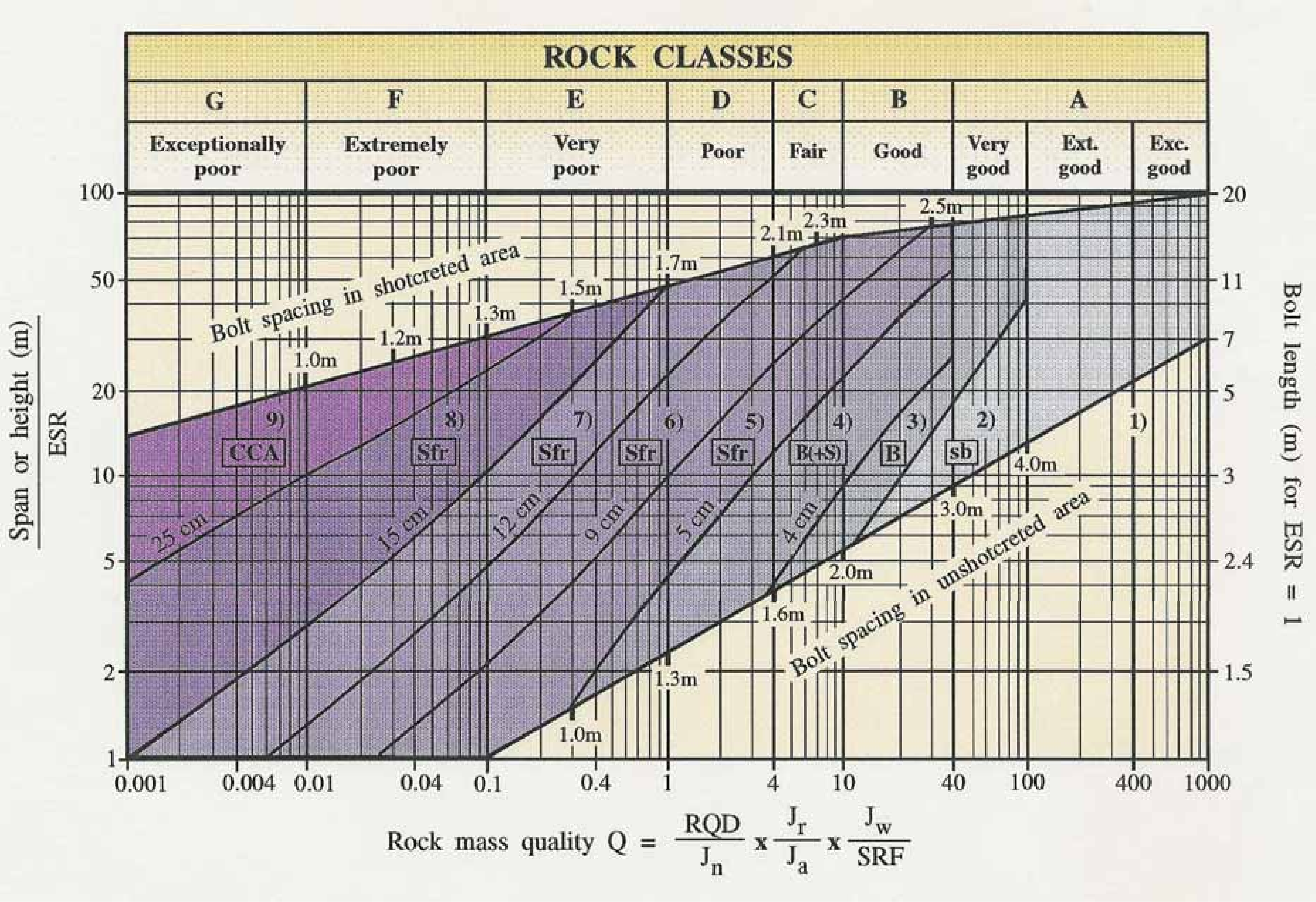


AN EXAMPLE OF DATA COLLECTION USING THE SIX Q-PARAMETERS IN AN EXPERIMENTAL TUNNEL (ÄSPÖ, SKB)



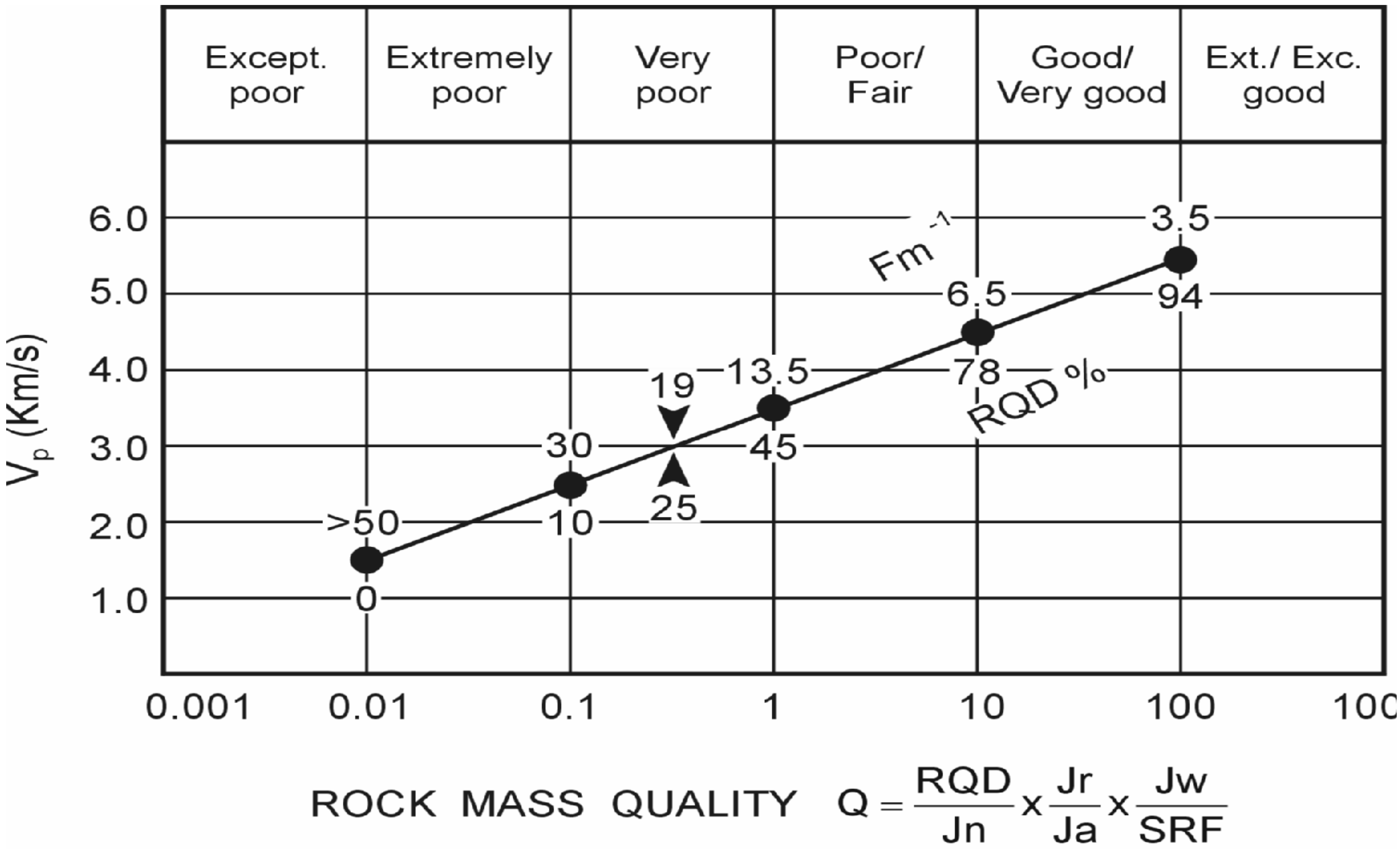
SUCH DATA HAVE MANY POTENTIAL (EMPIRICAL) USES IN ROCK ENGINEERING………

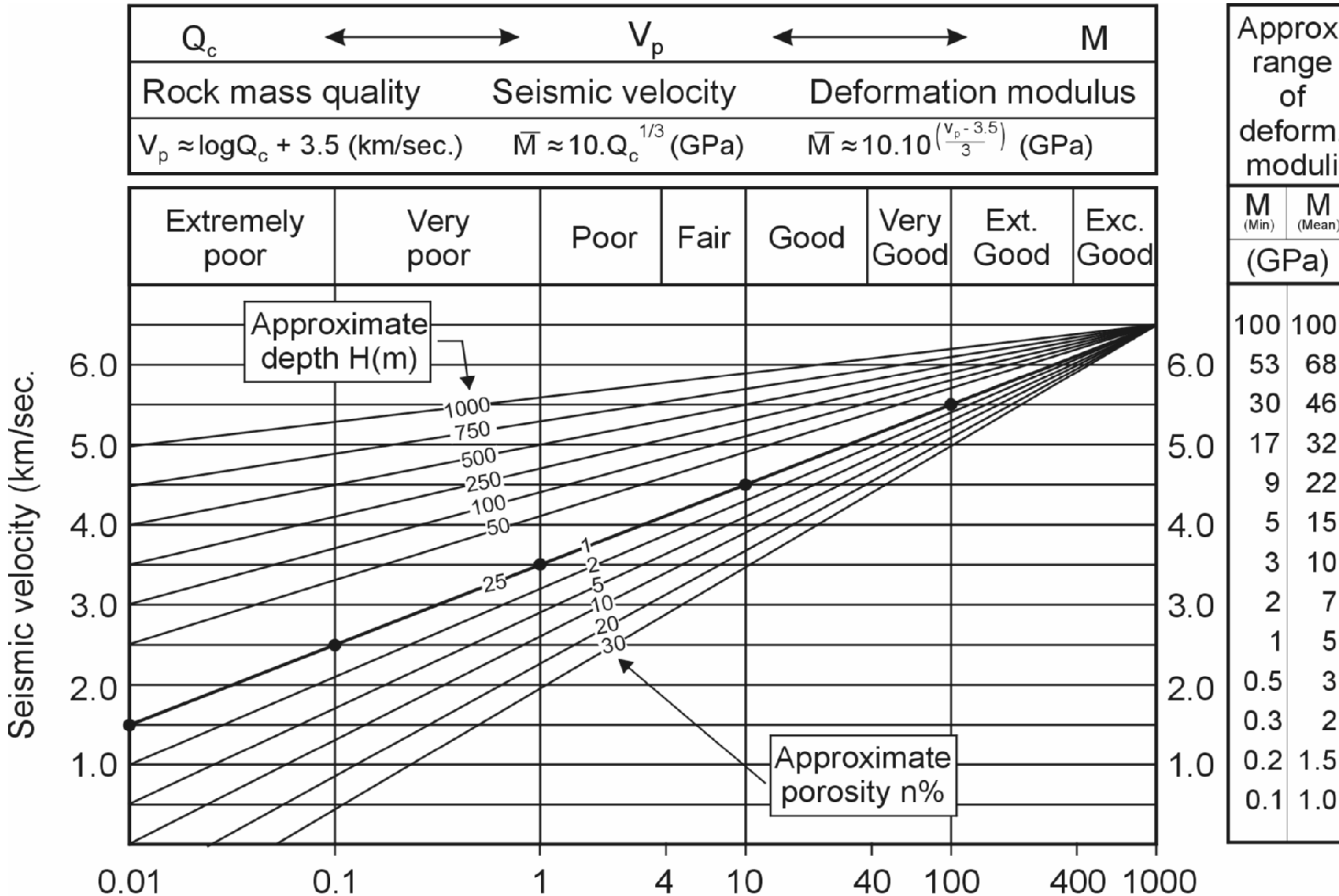
SUPPORT SELECTION for Drill-and-Blast TUNNELS



NEAR-SURFACE Q-Vp CORELLATION

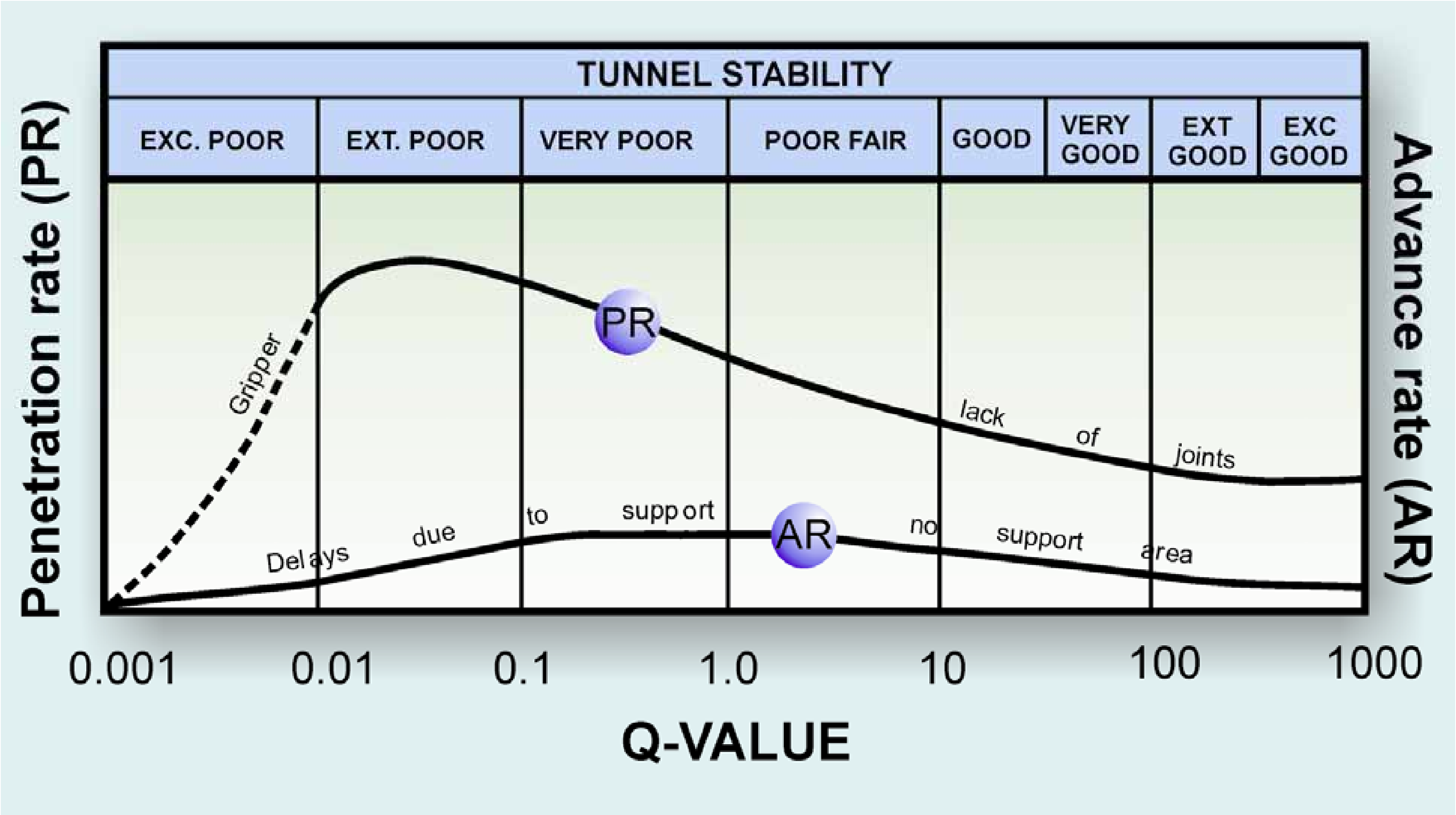
$$Vp = 3.5 + \log Q$$

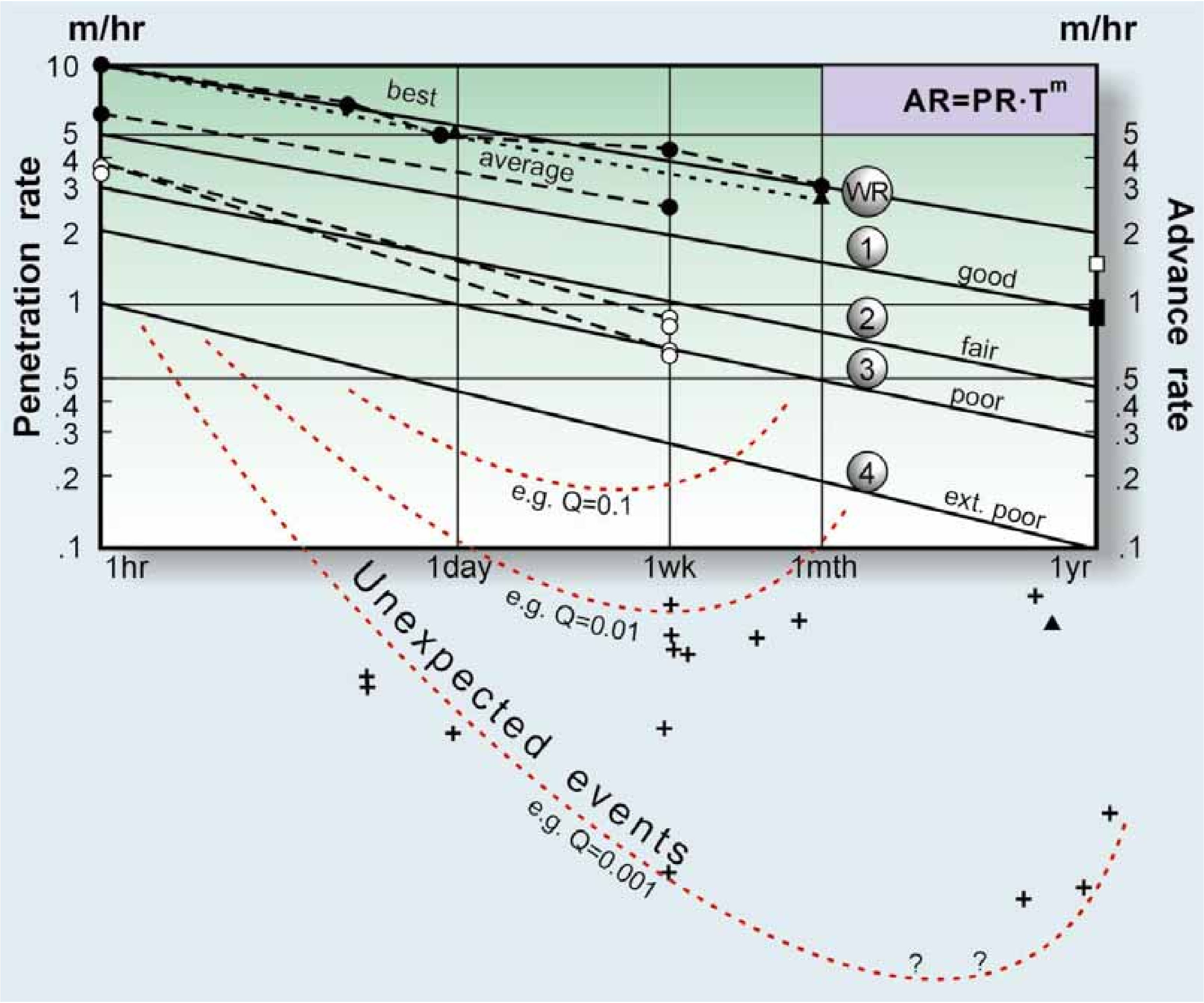




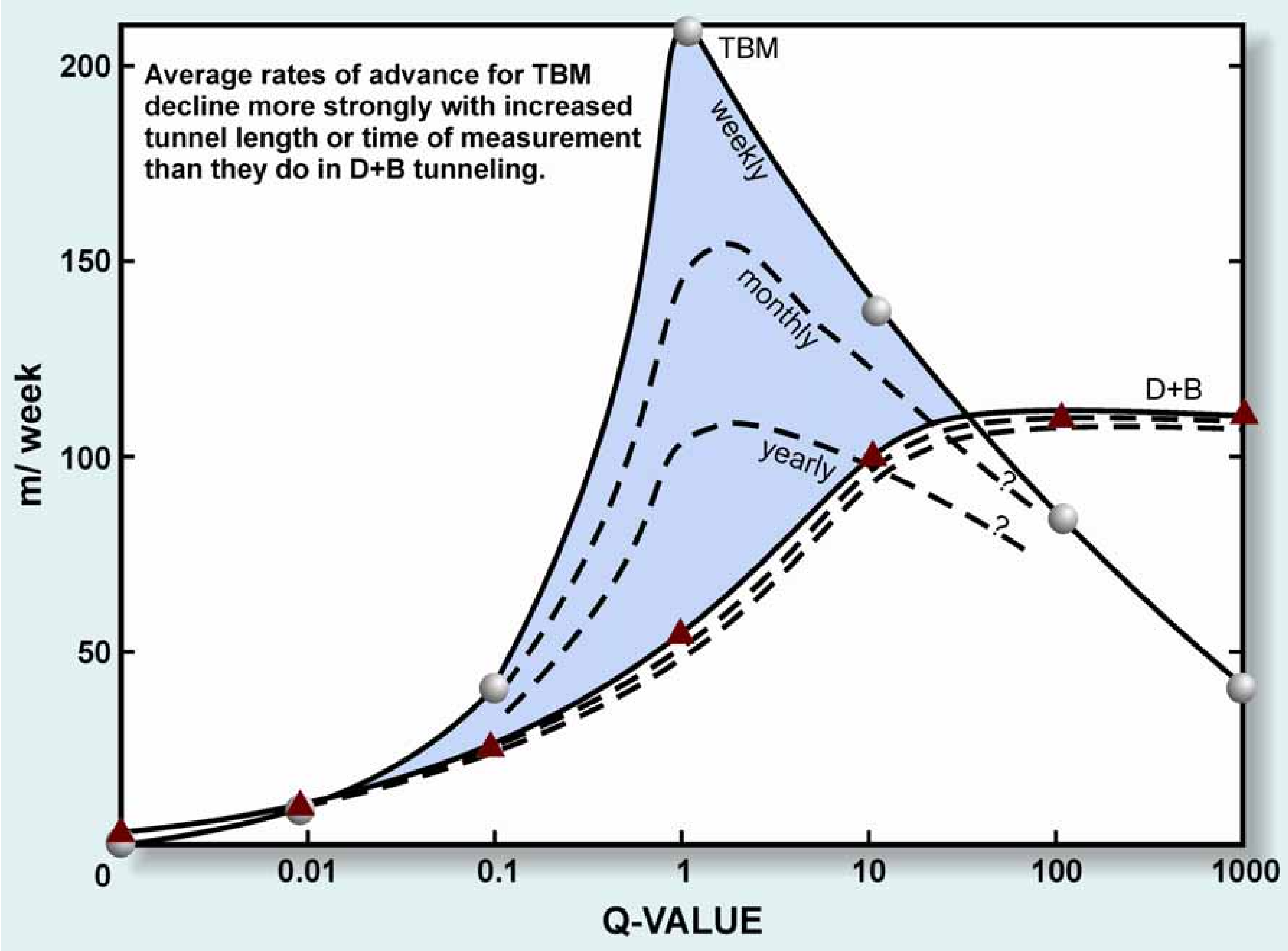
$$Q_c = \left[\frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \right] \frac{\sigma_C}{100}$$

THE SIX Q-PARAMETERS ARE ALSO OF GENERAL USE WHEN PLANNING (AND FOLLOWING-UP) TBM TUNNELS





NOTE THE 'UNEXPECTED' EVENTS, WITH LOW Q-VALUES

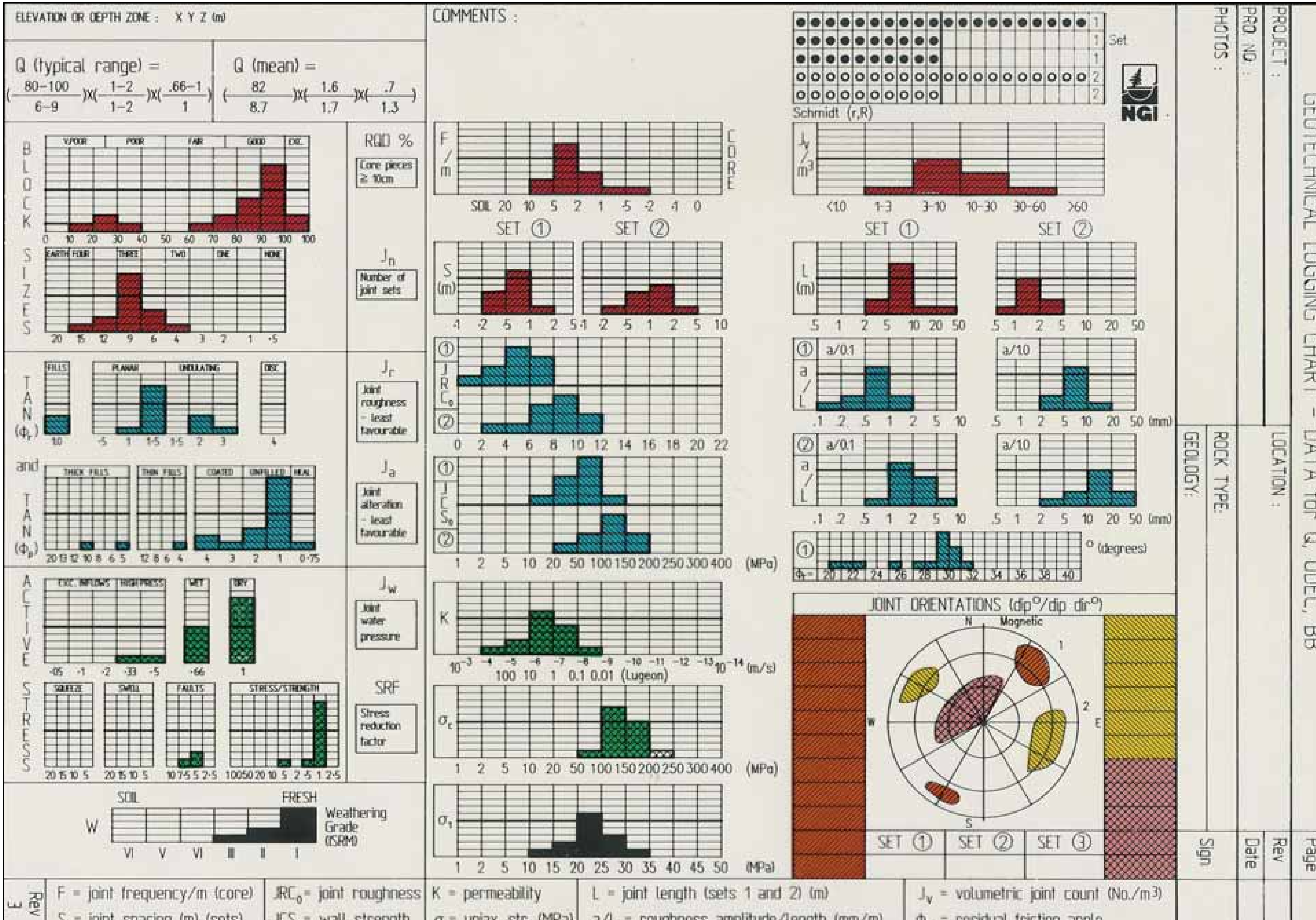


MIDDLE-RANGE Q-VALUES BEST FOR TBM !

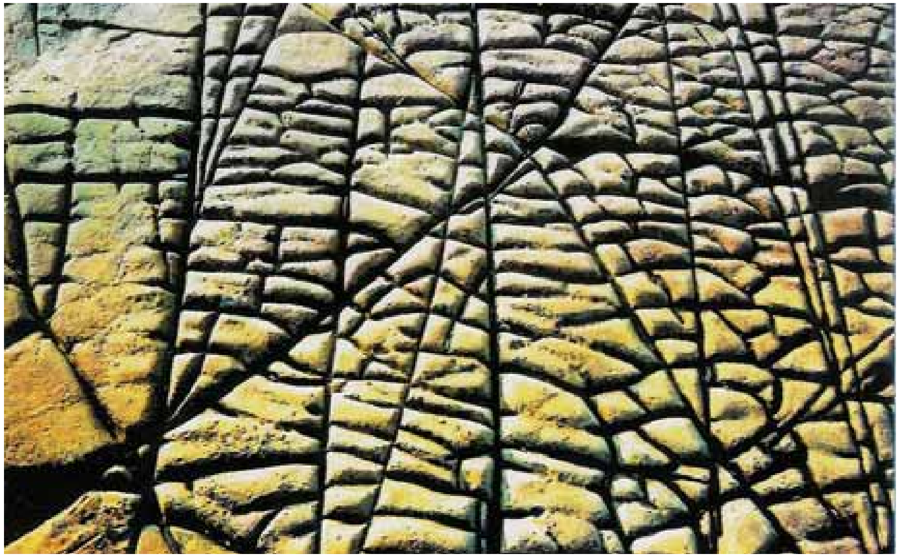
OBVIOUSLY THE ***SIX Q-PARAMETERS*** ARE JUST A SMALL FRACTION OF THOSE REQUIRED TO DESCRIBE A ROCK MASS IN ENOUGH DETAIL :

- FOR ***NUMERICAL MODELLING***
- FOR ANALYTICAL DESIGN
- FOR SITE DOCUMENTATION
- FOR DETAILED TBM PROGNOSIS

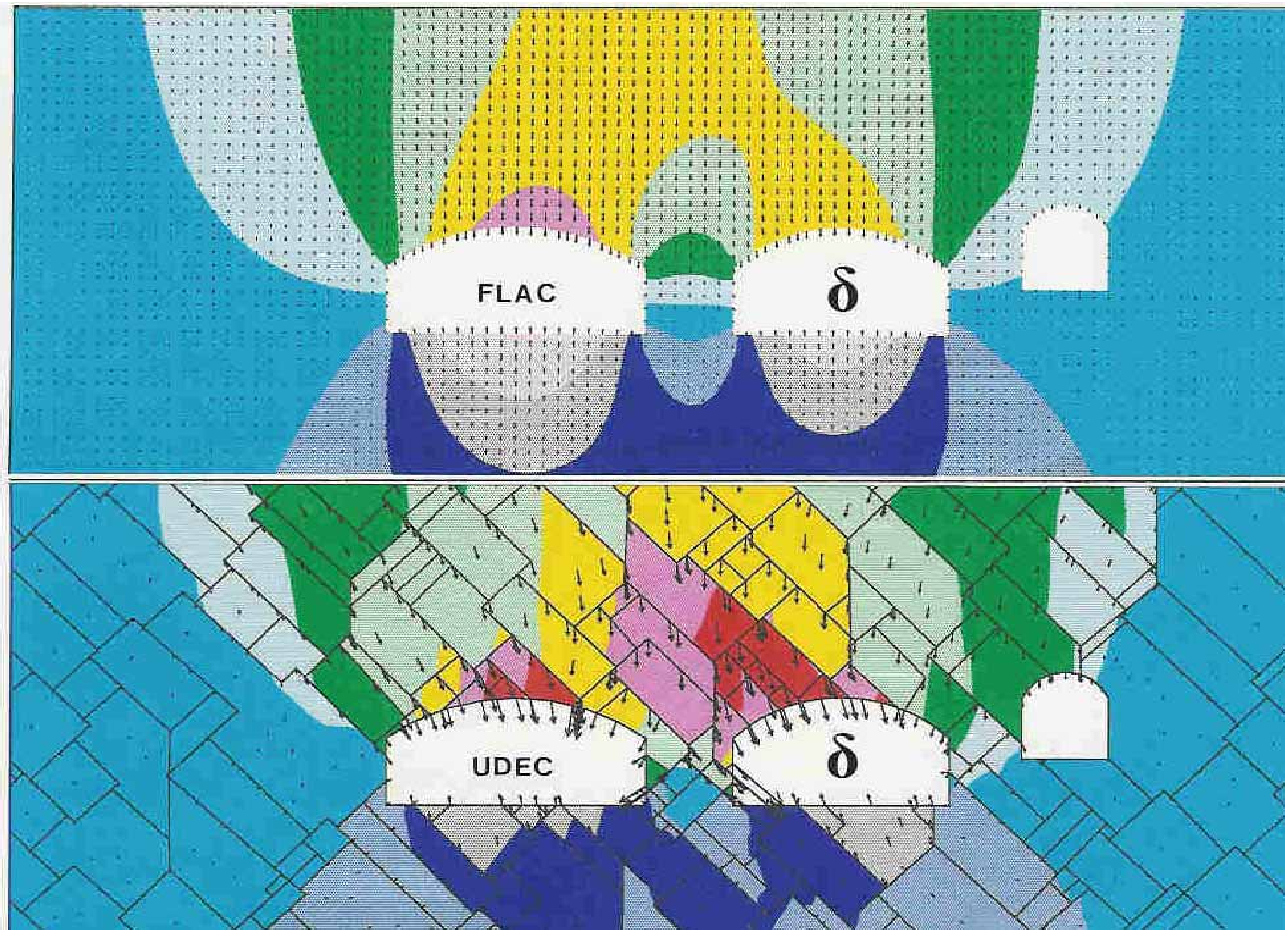
THE NEXT SCREEN SHOWS AN EXTENDED CHARACTERIZATION METHOD, WHICH **IS** USEFUL FOR NUMERICAL MODELLING AND FOR GENERAL DOCUMENTATION


GEOTECHNICAL LOGGING CHART – DATA for Q, UDEC, BB
PROJECT :
PRO. NO. :
PHOTOS :
LOCATION :
ROCK TYPE:
GEOLOGY:
Sign
Date
Rev
Page
NGI
ELEVATION OR DEPTH ZONE : X Y Z (m)
Q (typical range) = (80–100 / 6–9)x(1–2 / 1–2)x(.66–1 / 1)
Q (mean) = (82 / 8.7)x(1.6 / 1.7)x(.7 / 1.3)
COMMENTS :
BLOCK SIZES
V.POOR
POOR
FAIR
GOOD
EXC.
RQD %
Core pieces ≥ 10cm
EARTH
FOUR
THREE
TWO
ONE
NONE
Jn
Number of joint sets
TAN (Φr) and TAN (Φp)
FILLS
PLANAR
UNDULATING
DISC
Jr
Joint roughness – least favourable
THICK FILLS
THIN FILLS
COATED
UNFILLED
HEAL
Ja
Joint alteration – least favourable
ACTIVE STRESS
EXC. INFLOWS
HIGH PRESS.
WET
DRY
Jw
Joint water pressure
SQUEEZE
SWELL
FAULTS
STRESS/STRENGTH
SRF
Stress reduction factor
SOIL
FRESH
W
Weathering Grade (ISRM)
F / m
CORE
SOIL 20 10 5 2 1 .5 .2 .1 0
SET ①
SET ②
S (m)
JRC0
JCS0
1 2 5 10 20 50 100 150 200 250 300 400 (MPa)
K
10^{-3} −4 −5 −6 −7 −8 −9 −10 −11 −12 −13 10^{-14} (m/s)
100 10 1 0.1 0.01 (Lugeon)
σc
σ1
1 2 5 10 15 20 25 30 35 40 45 50 (MPa)
Set
Schmidt (r,R)
Jv / m3
<1.0 1-3 3-10 10-30 30-60 >60
L (m)
a / L
a/0.1
a/1.0
(mm)
° (degrees)
Φr = 20 22 24 26 28 30 32 34 36 38 40
JOINT ORIENTATIONS (dip°/dip dir°)
N
Magnetic
W
E
S
SET ①
SET ②
SET ③
Rev 3
F = joint frequency/m (core)
S = joint spacing (m) (sets)
JRC0 = joint roughness
JCS0 = wall strength
K = permeability
σc = uniax. str. (MPa)
L = joint length (sets 1 and 2) (m)
a/L = roughness amplitude/length (mm/m)
Jv = volumetric joint count (No./m3)
Φr = residual friction angle

When contemplating numerical modelling…of jointed rock…one should concentrate on the longest, least rough joint sets….they will often have the lowest values of JRC_n and JCS_n and $\varphi_{r.}$ The shorter, rougher, stronger joints will however reduce deformation modulus, so must be included implicitly.

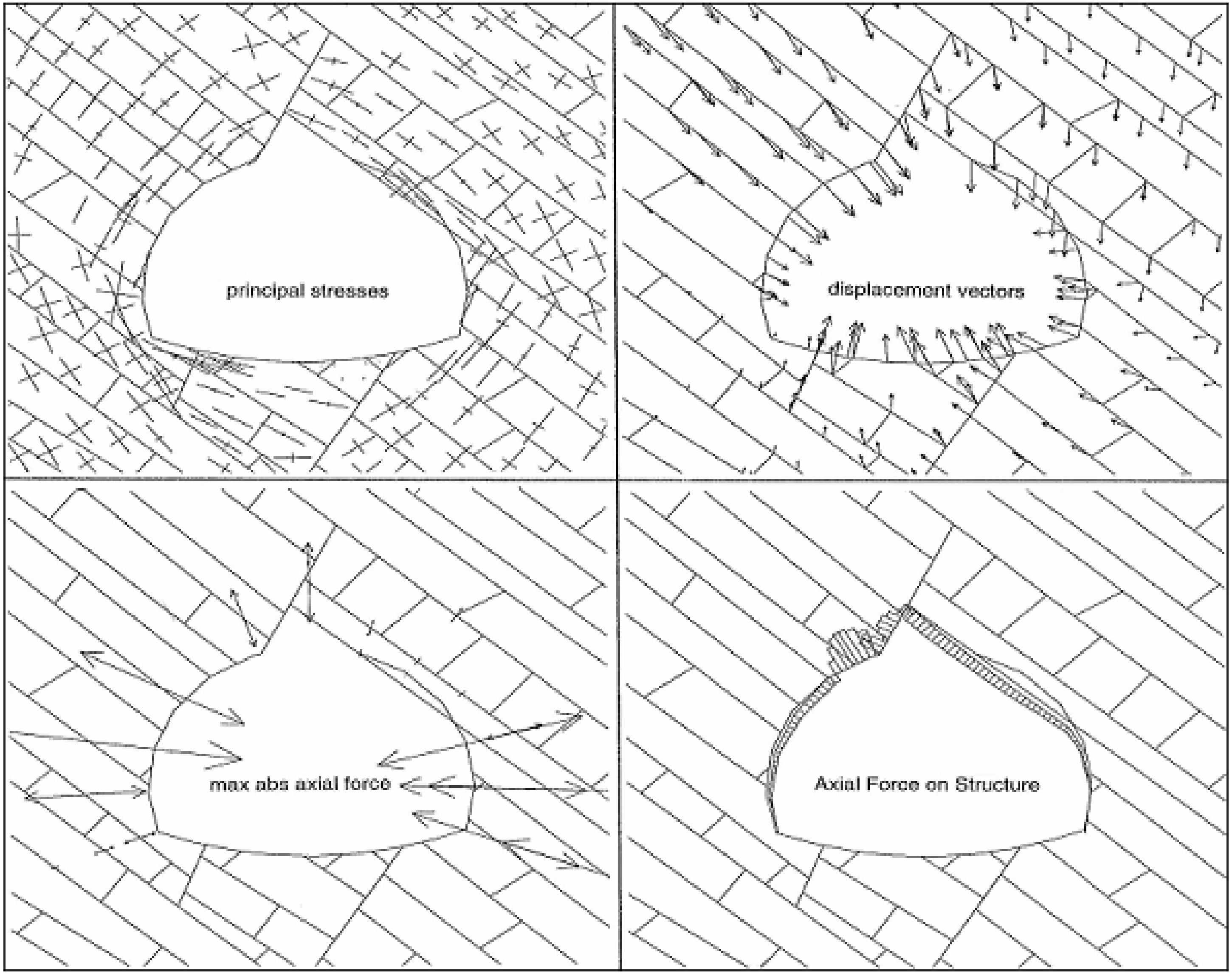


THE NUMERICAL MODEL…..TWO OF MANY OPTIONS

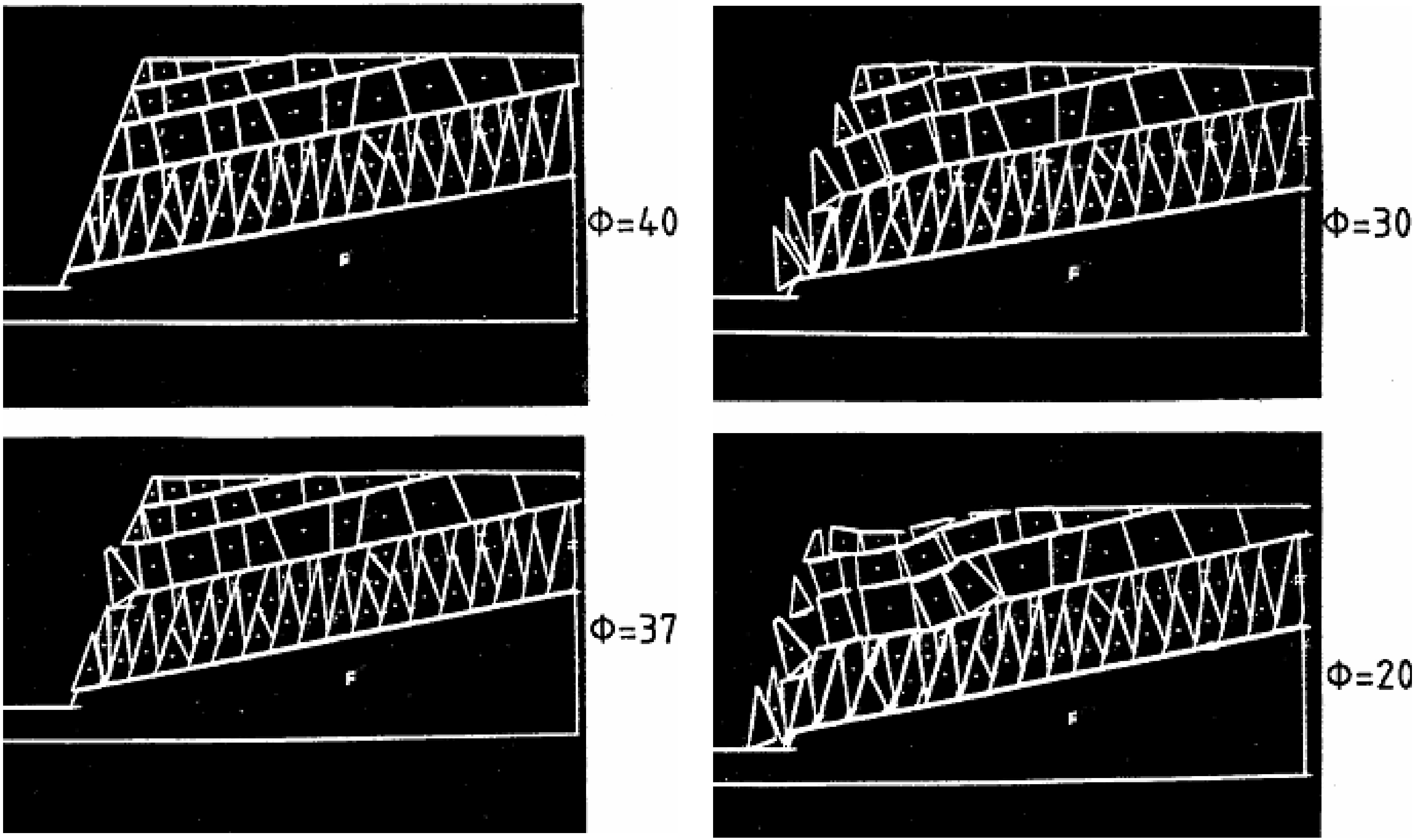


PREFERABLY A DISCONTINUUM MODEL LIKE UDEC / UDEC-BB
……TO CAPTURE THE EFFECTS OF JOINT DEFORMATION

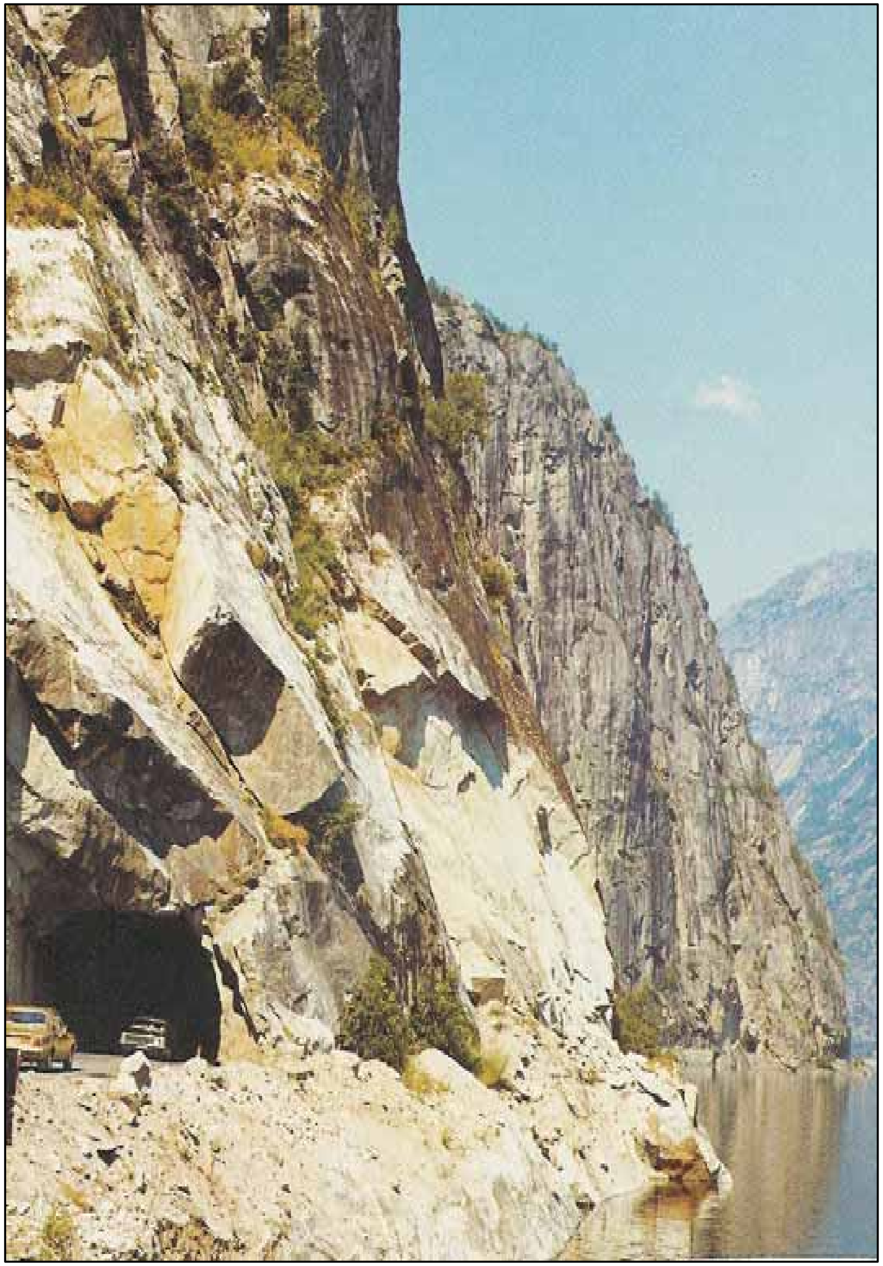
STRESSES, DISPLACEMENTS, BOLT TENSIONS, AXIAL FORCES IN S(fr) SHOTCRETE (showing poor bonding on bedding planes)

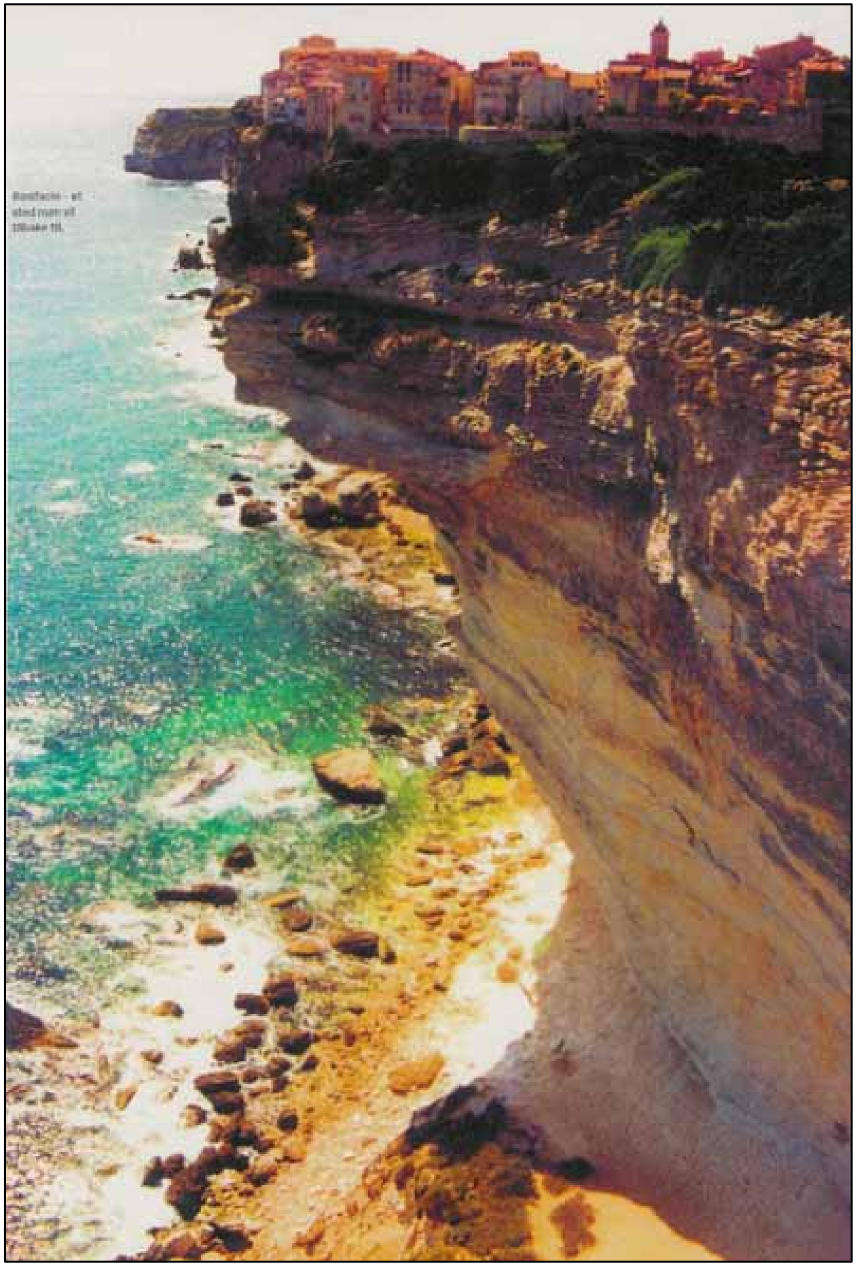


AN EARLY (1975) ***rigid block*** *DEMONSTRATION OF THE NEED FOR RELEVANT INPUT DATA (Cundall and Voegle)*



FAILURE OF INTACT ROCK – NOT SO EASY TO MODEL

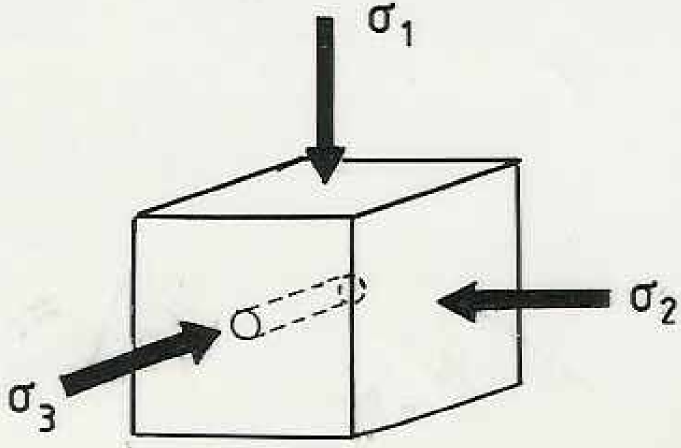


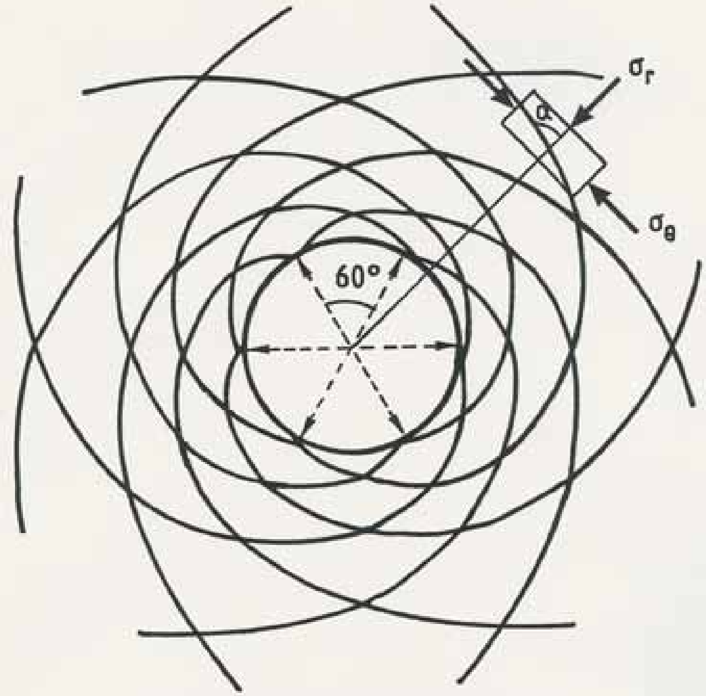


SLOPE FAILURES CAUSED BY (TOO) HIGH STRESS/STRENGTH RATIOS ARE ‘IMPRESSIVE’…. BUT WHAT ABOUT BOREHOLES AND TUNNELS ?


(ITA hydroelectric project, Brazil……stress concentration in ridge)

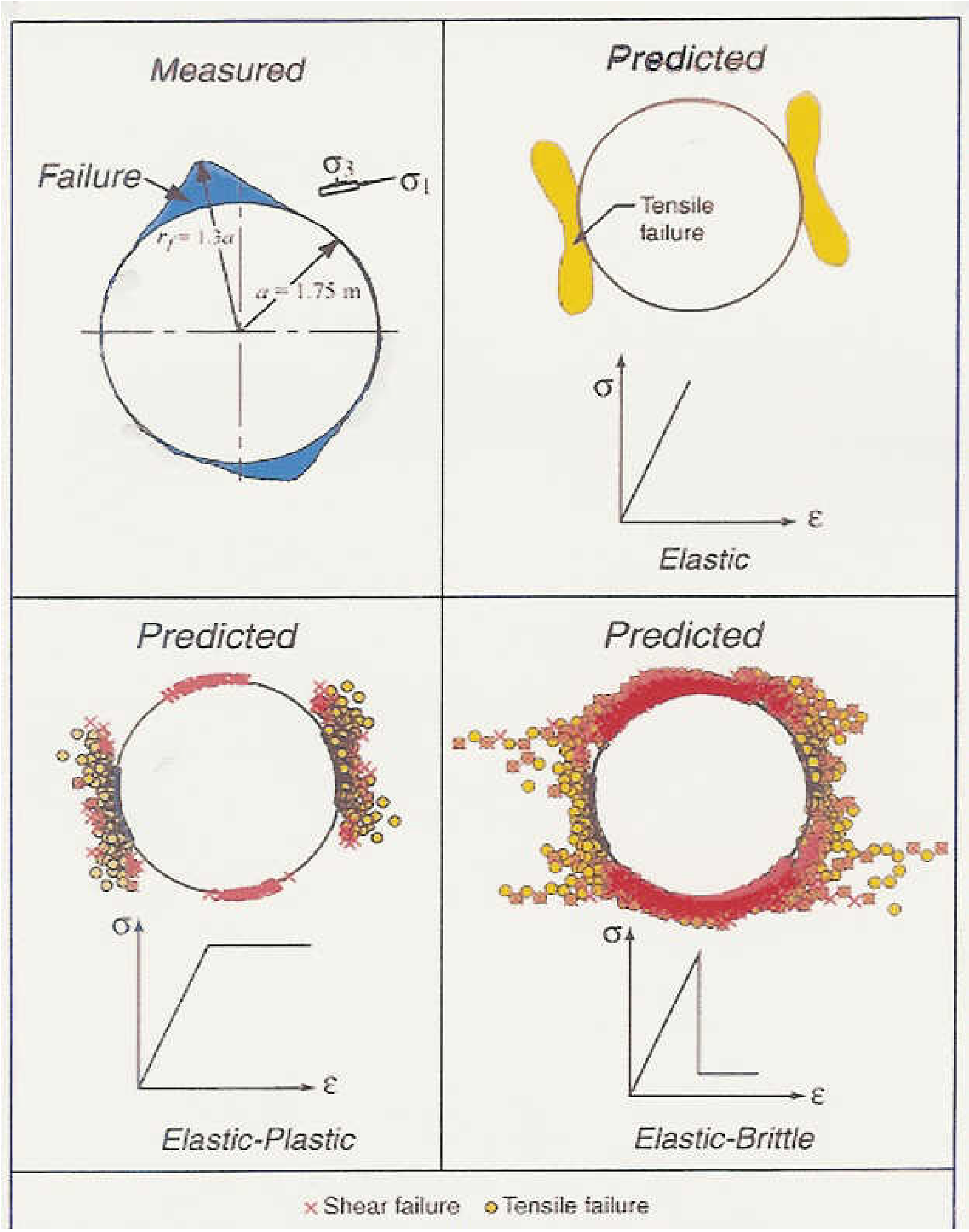
LOG-SPIRAL FAILURE MODES….EXPERIMENTAL BOREHOLES





JOINT-RELATED FALL-OUT……AND STRESS ?

STRESS-RELATED CRUSHING OF WALLS IN CHALK-MARL



SOME (POOR) ATTEMPTS AT MODELLING (URL) 'DOG-EARING'

(with standard continuum model and MC or HB failure criteria)

Martin et al. 2002.

A FLAC continuum model using degradation of cohesion and mobilization of friction.

(Deidrichs, reported in Martin et al. 2002)

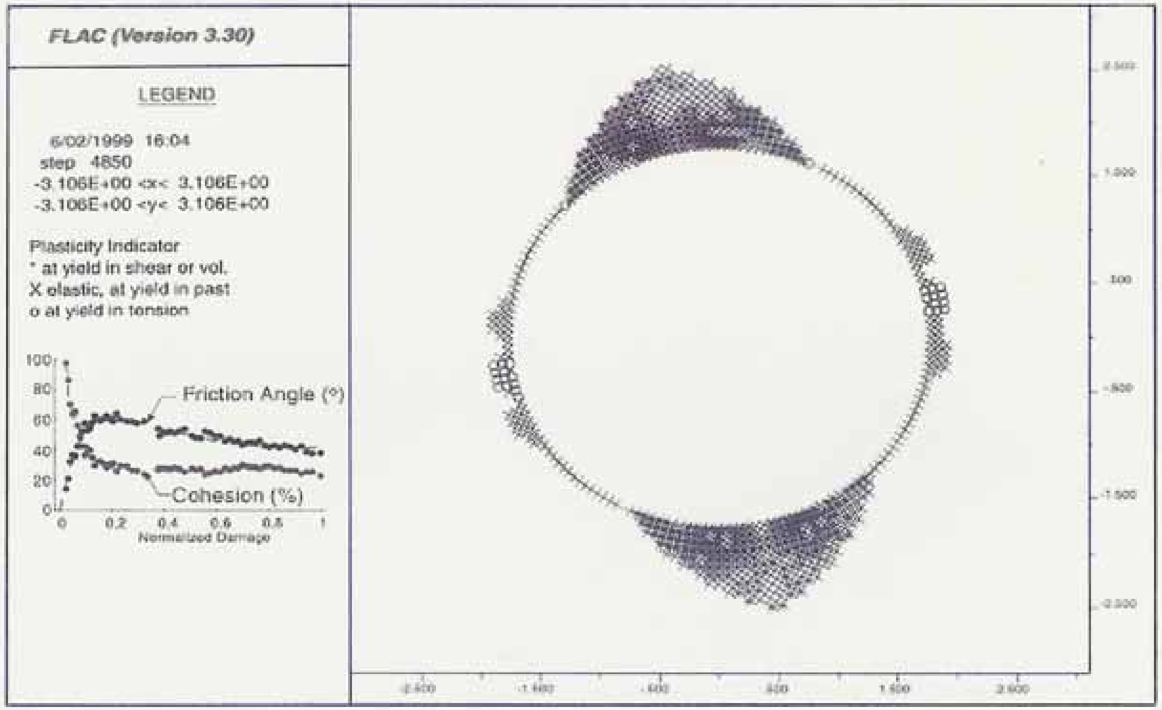
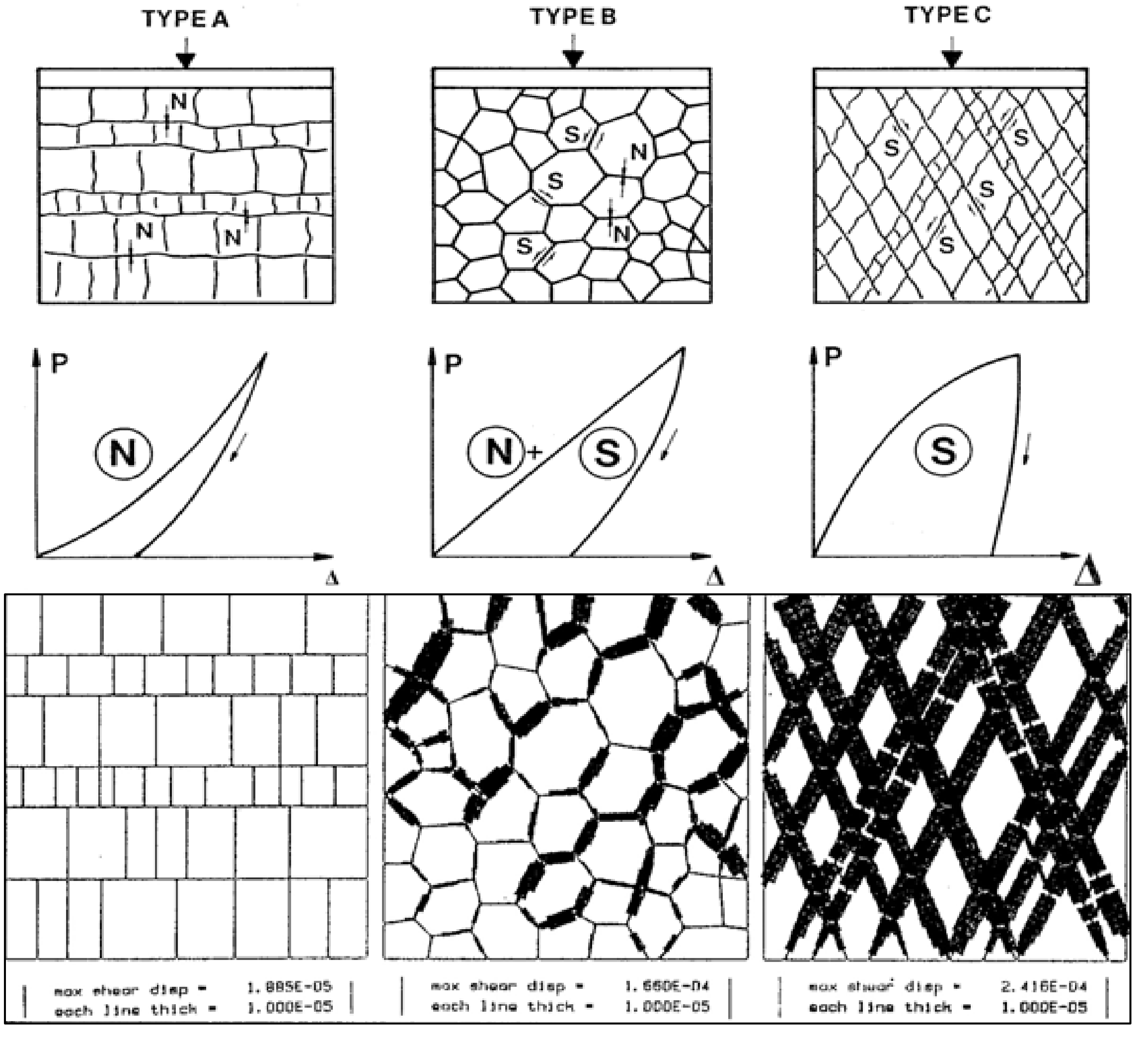


Figure 1: The difficulties of modelling rock failure behaviour with continuum models. The three predicted cases (top) were obtained using PHASES. The bottom one involved FLAC and a manual execution of reducing cohesion and increasing friction – as exhibited in nature in the case of rock. Only this case was close to the measured behaviour at the AECL Underground Research Lab. (Martin et al. 2002).

QUESTIONS ?

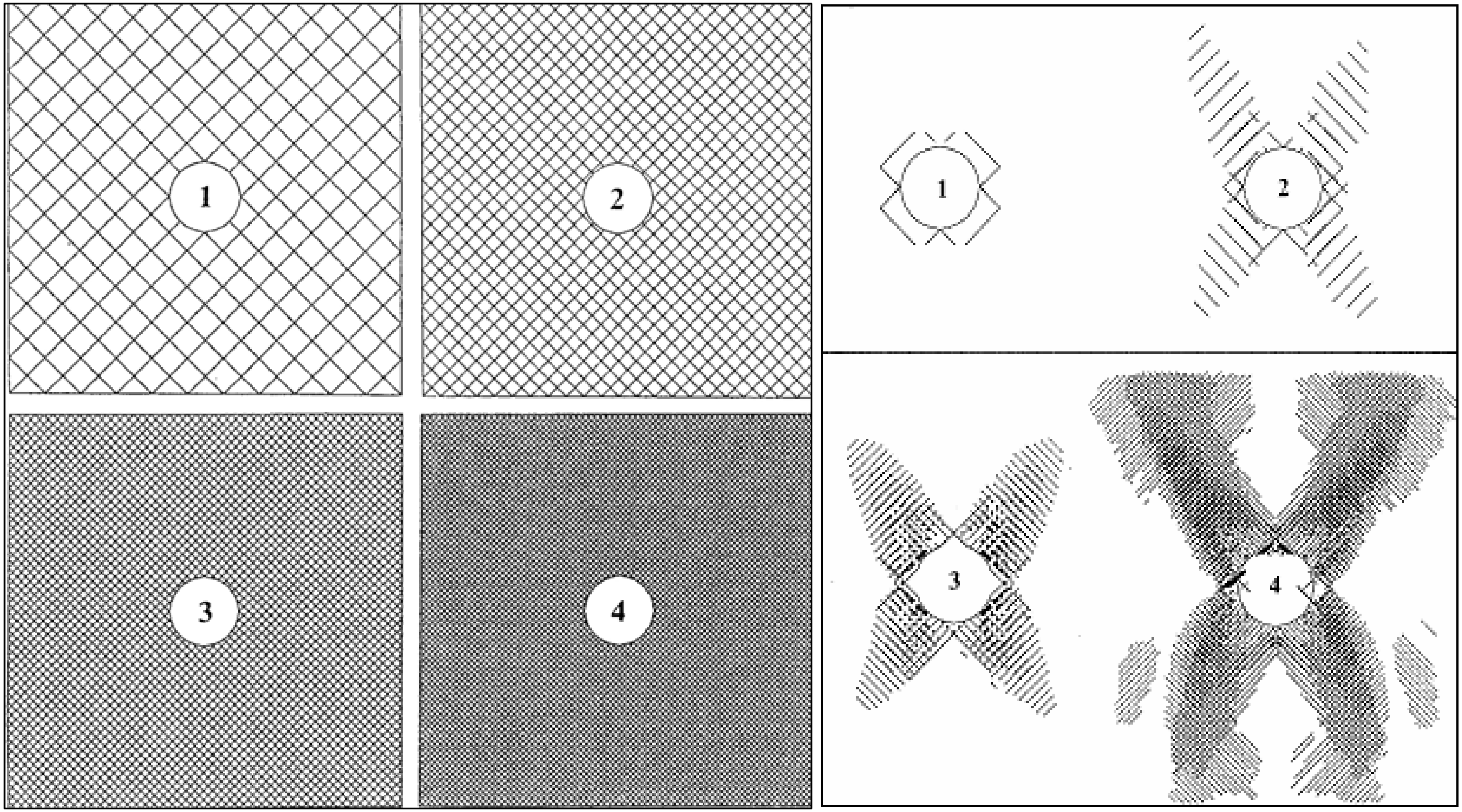
1. *WHERE ARE MODELS THAT DEVELOP LOG **SPIRAL FAILURE** SURFACES ?*

2. *WHERE ARE OUR FAILURE CRITERIA THAT ACKNOWLEDGE THE DIFFERENT STRAINS INVOLVED WHEN 'BREAKING' **COHESION** AND 'MOBILIZING' **FRICTION** ?*

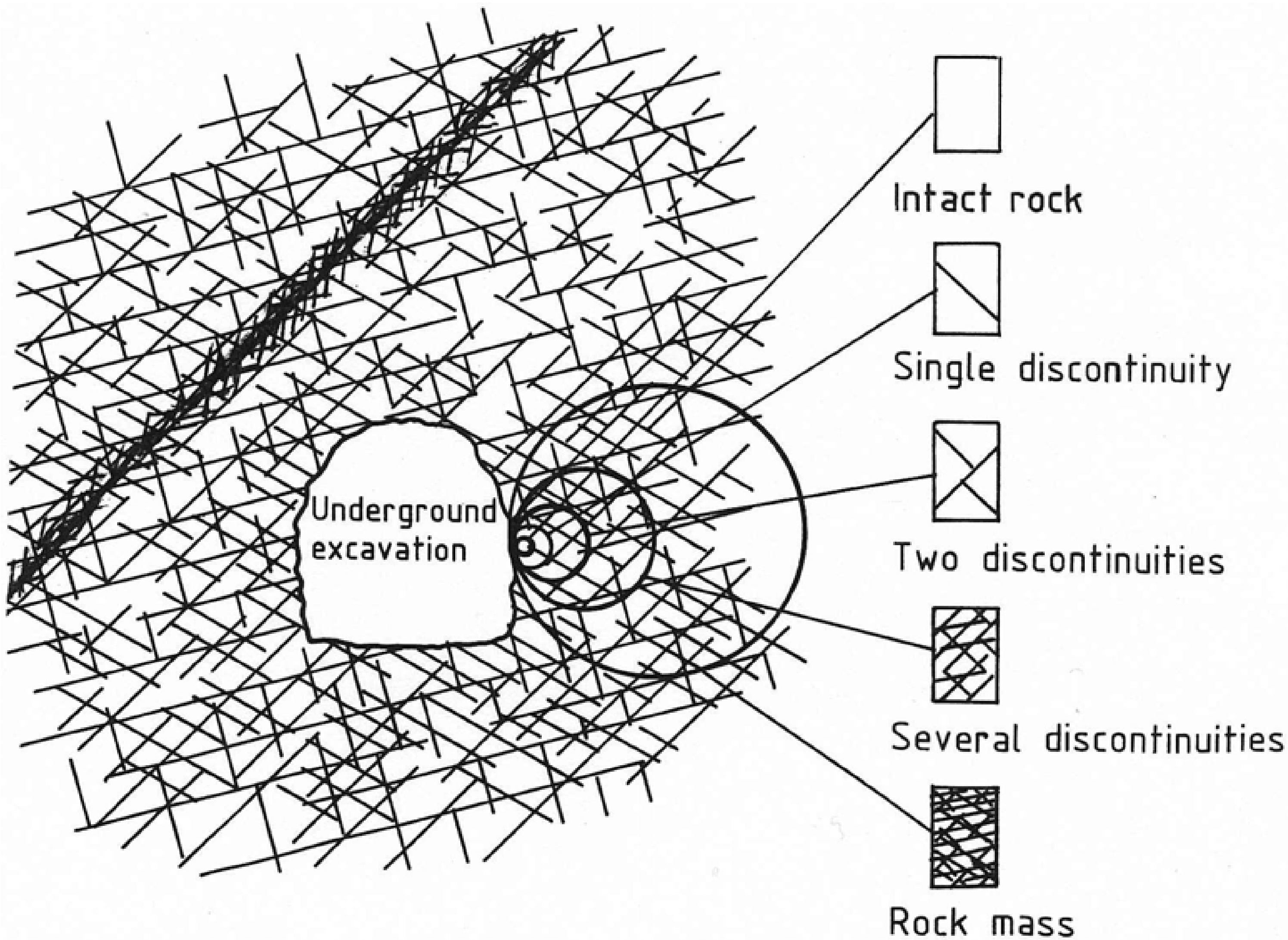


WHEN CONSIDERING CONTINUUM ANALYSES (???)……
ONE SHOULD BE AWARE OF HOW MANY DETAILS ARE LOST !

PRESUMABLY THESE UDEC-MC MODELS ALSO SHOW HIGHER (local) ''POISSON'S RATIOS'' THE SMALLER THE BLOCK SIZE. ARE CONTINUUM MODELS IN FACT DEFENSIBLE…..WHEN THERE ARE A LOT OF BLOCKS ?

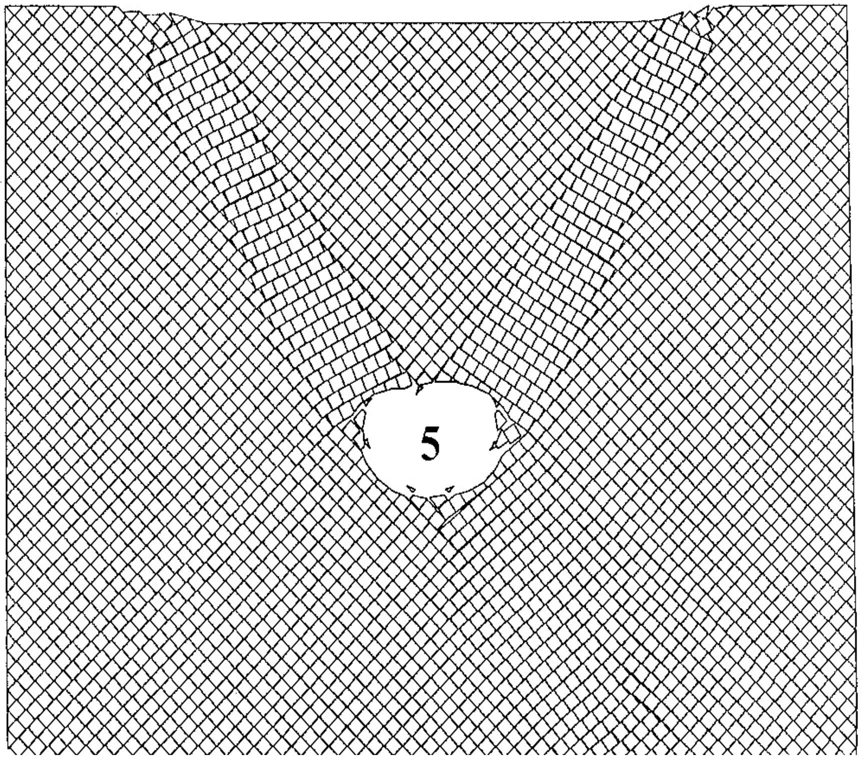


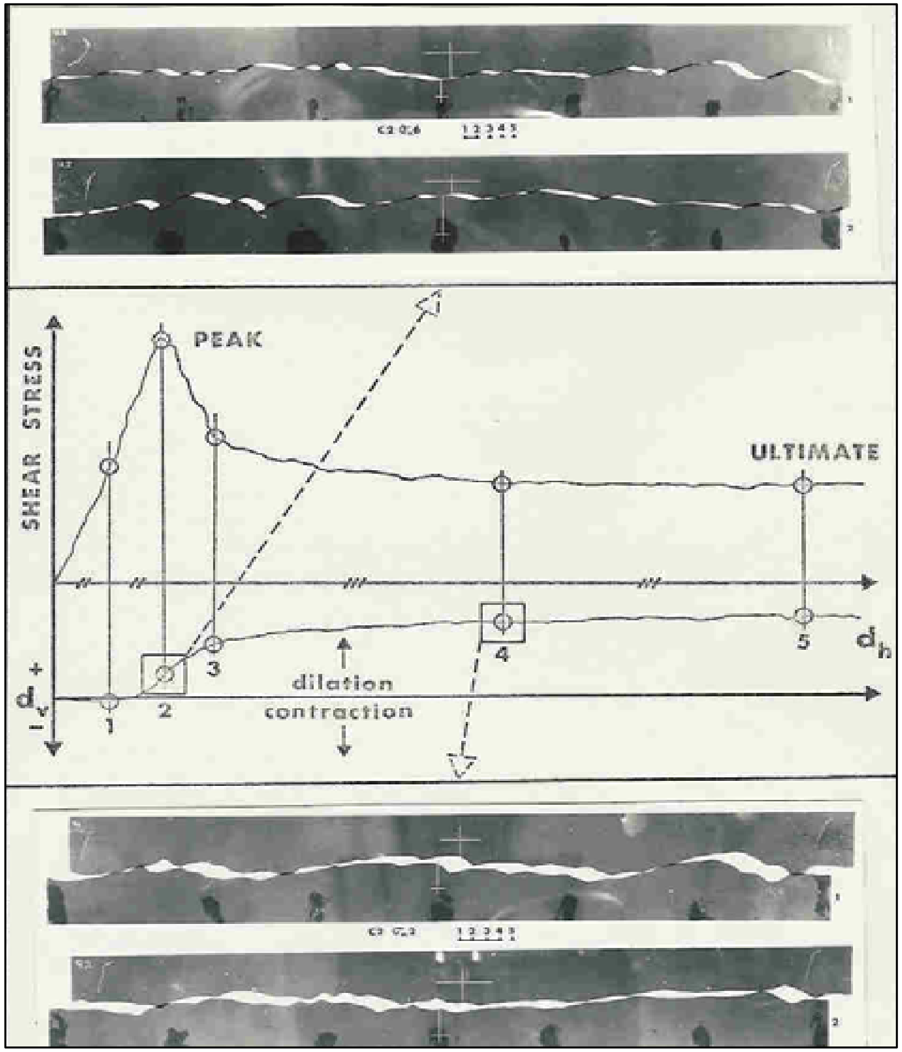
(400, 1000, 4000, 10,000 blocks. UDEC-MC, Baotang Shen)



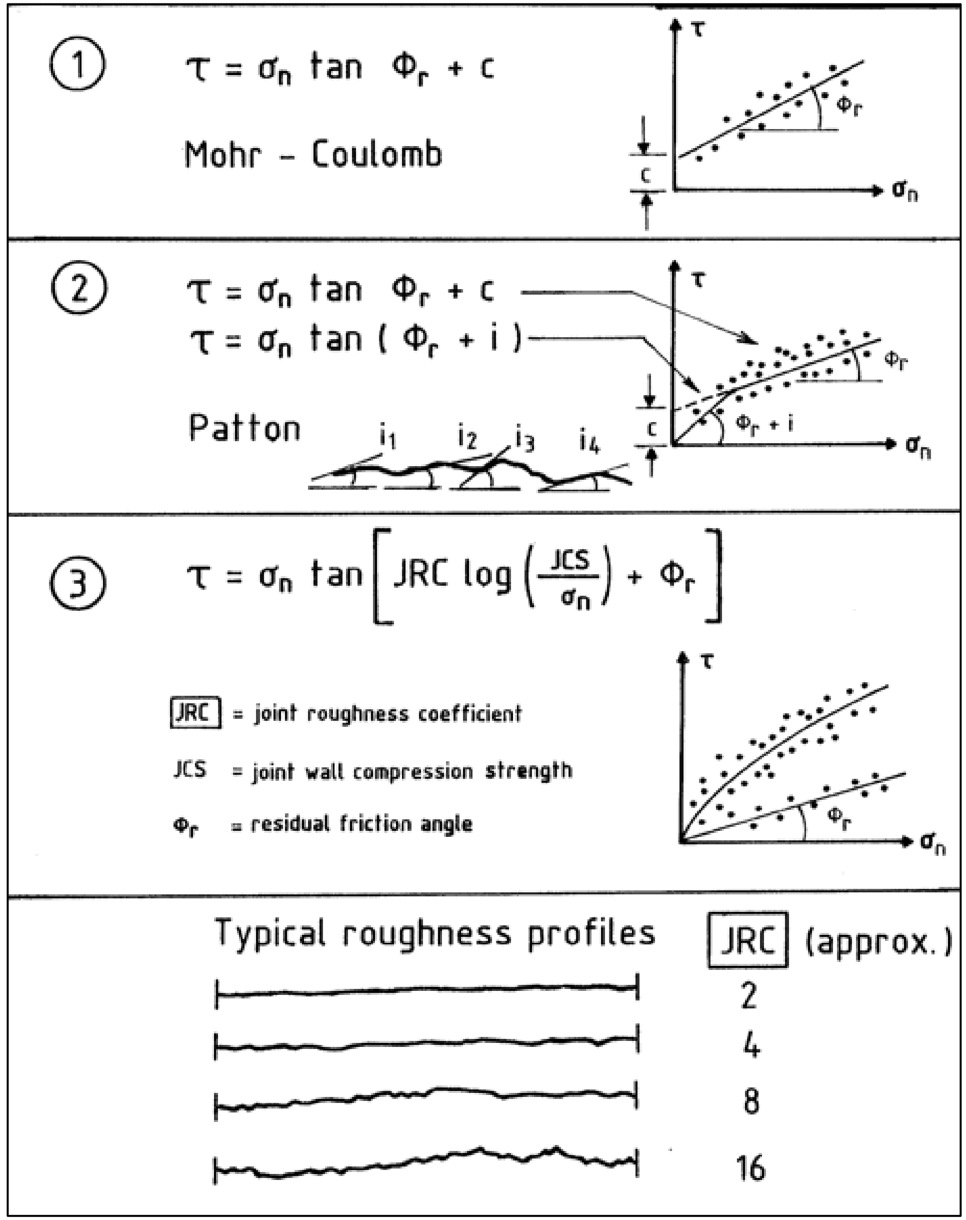
HOEK'S DRAWING OF 'THE SCALE OF THE PROBLEM '…..
AND THE PRESUMED NEED FOR DIFFERENT MODELLING METHODS
(ARE WE SURE CONTINUUM MODELS ARE 'OK' FOR THE '*ROCK MASS' ?)*

ARE THE ABOVE DEFORMATION PHENOMENA THE REASON FOR 4 TO 5 DIAMETER TUNNEL-PILLARS e.g. in JAPAN and TAIWAN etc.?



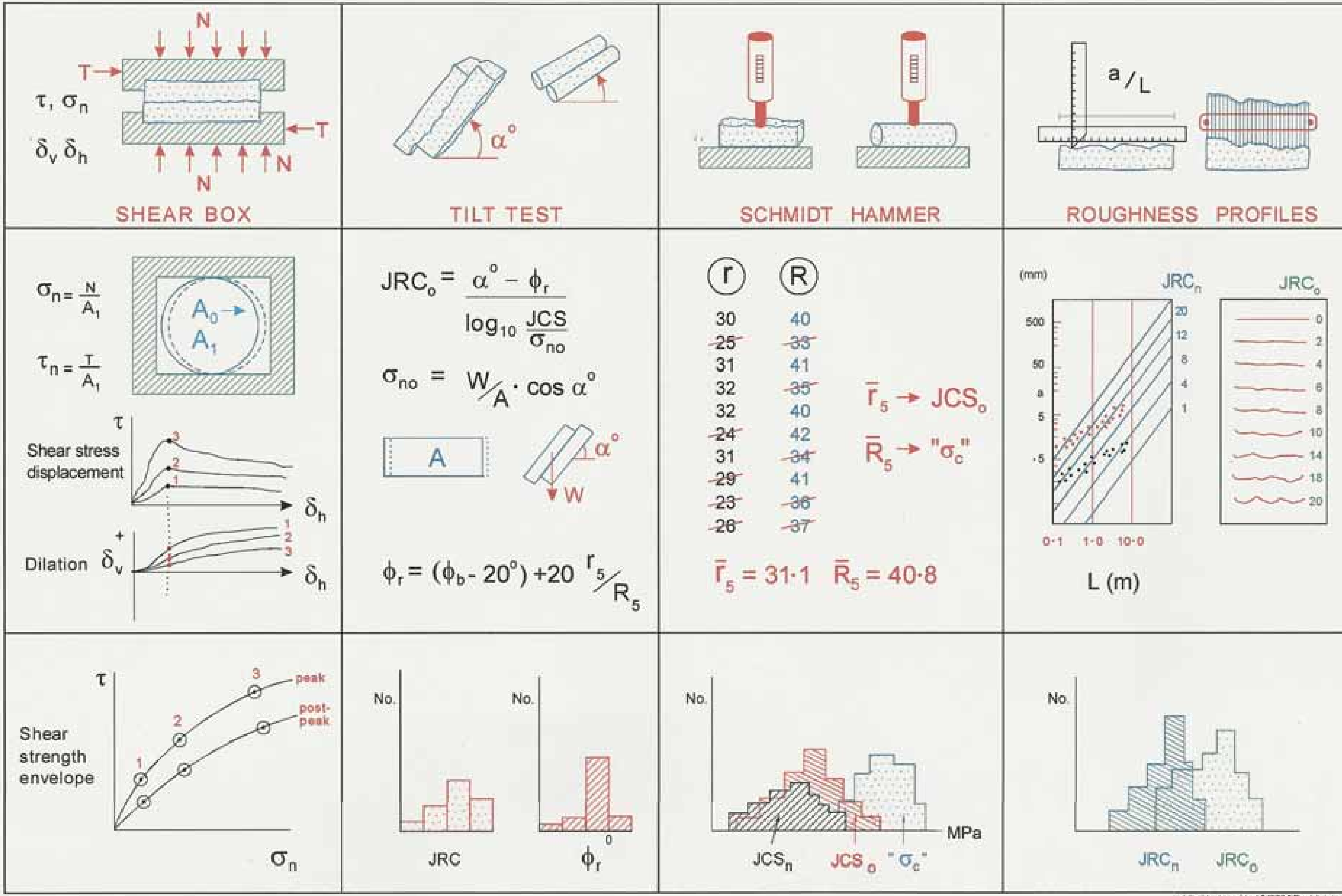


THESE ARE RECONSTRUCTED DIRECT SHEAR TESTS OF TENSION FRACTURES, WITH THE CORRECT ROUGHNESS, AND DILATION PATH



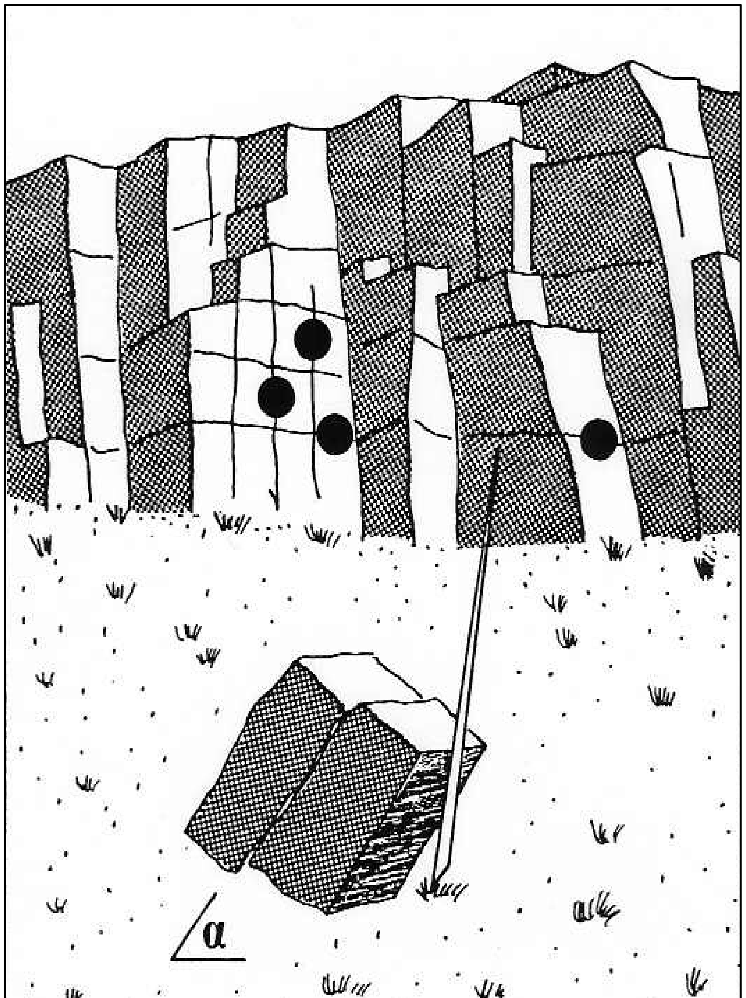
SOME YEARS LATER WE ARRIVED HERE (# 3)….WITH JRC, JCS and φ_R

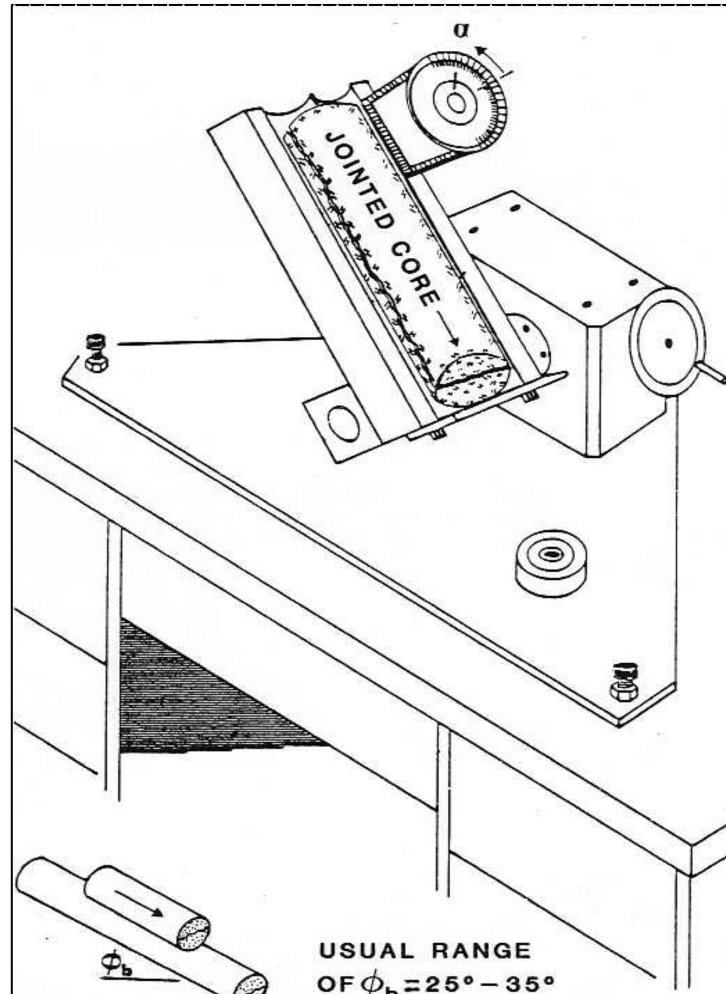
SHEAR BOX AND INDEX TESTING OF ROCK JOINTS



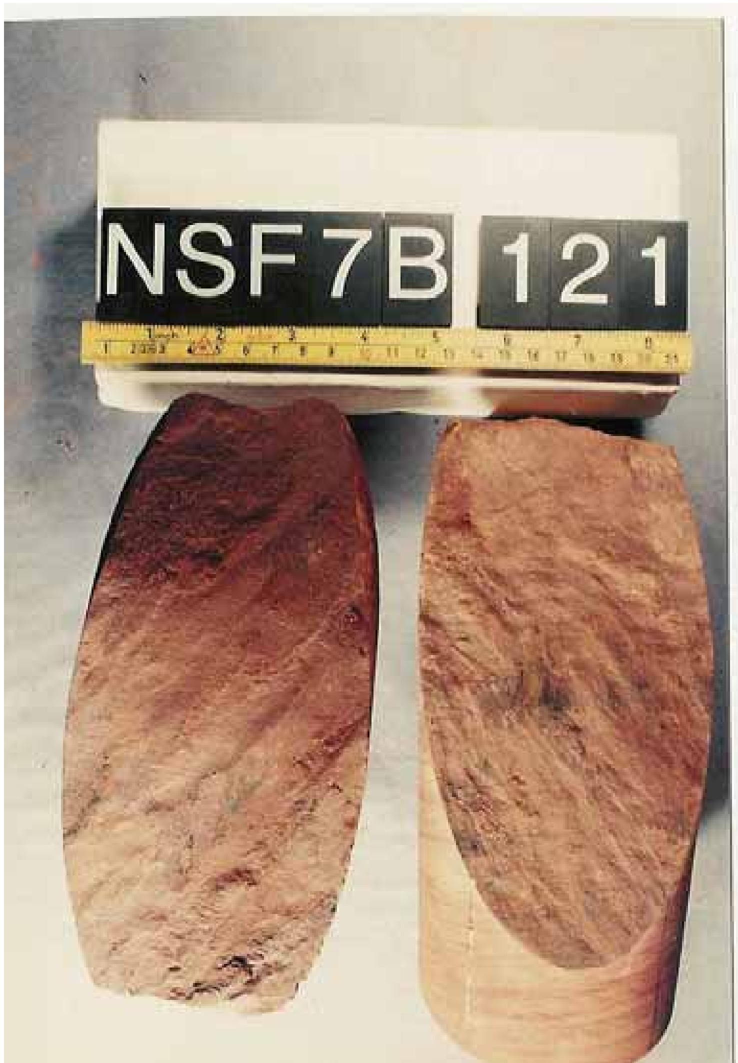
THE TILT TEST COULD TAKE MANY DIFFERENT FORMS – THERE ARE NUMEROUS VARIETIES…EVEN ONES MADE OF WOOD AND STRING !

(We have performed tilt tests on 1 m3 blocks…….and on 25 m3 rockfill samples at a dam site)



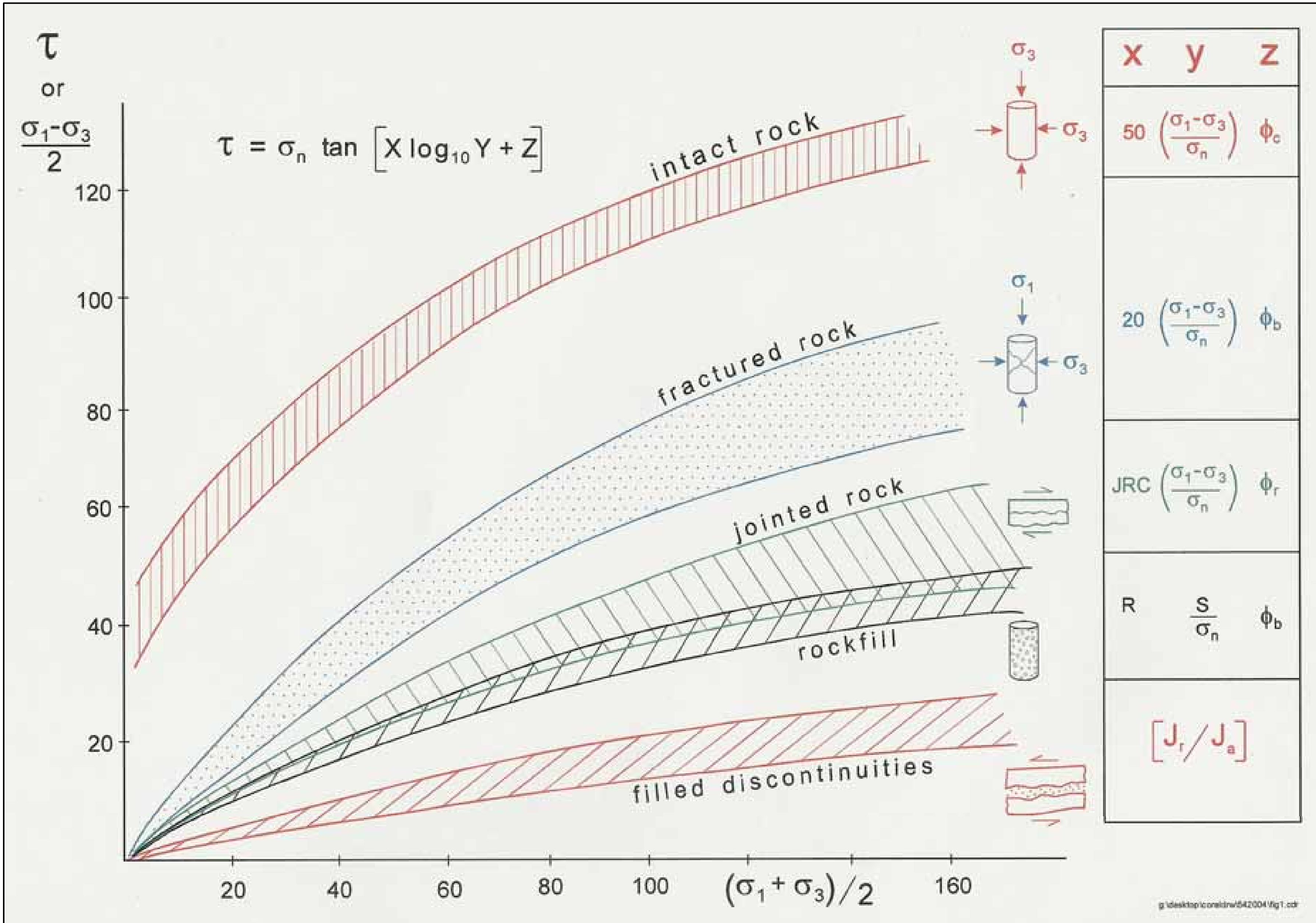


JOINT SURFACES ARE SOMETIMES QUITE ANISOTROPIC SO ONE WOULD NEED TO (TILT OR SHEAR) TEST IN RELEVANT DIRECTIONS IF THE RELEVANT DIRECTION WAS KNOWN (e.g. Jing Lanru)

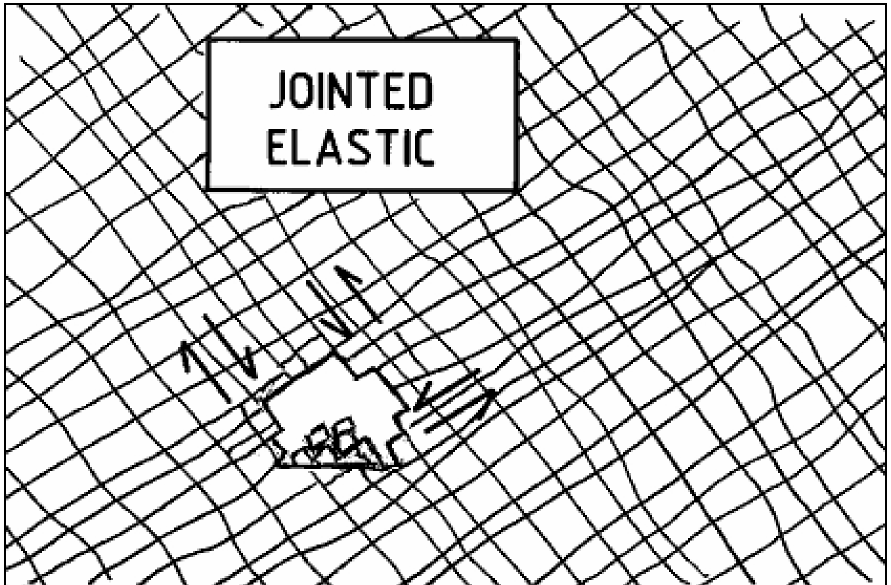


JCS ---THE JOINT WALL COMPRESSION STRENGTH…..IS USUALLY < σ_C

THERE IS A COMMON SUITE OF STRENGTH ENVELOPES……WHY $log_{10}y$???



TWO EXAMPLES OF THE STRENGTH ENVELOPES – FOR JOINTS AND CLAY



BARTON–BANDIS (scaled)

$$\tau = \sigma_n . \tan\left[JRC_n . \log\left(\frac{JCS_n}{\sigma_n}\right) + \Phi_r\right]$$

BARTON–LIEN–LUNDE

$$\tau = \sigma_n \left[J_r / J_a\right]$$

THE MOST IMPORTANT PROPERTY IS……DILATION (and all that implies)