Risk Assessment and Management for the Eagles Nest Tunnels, Route 8 Highway

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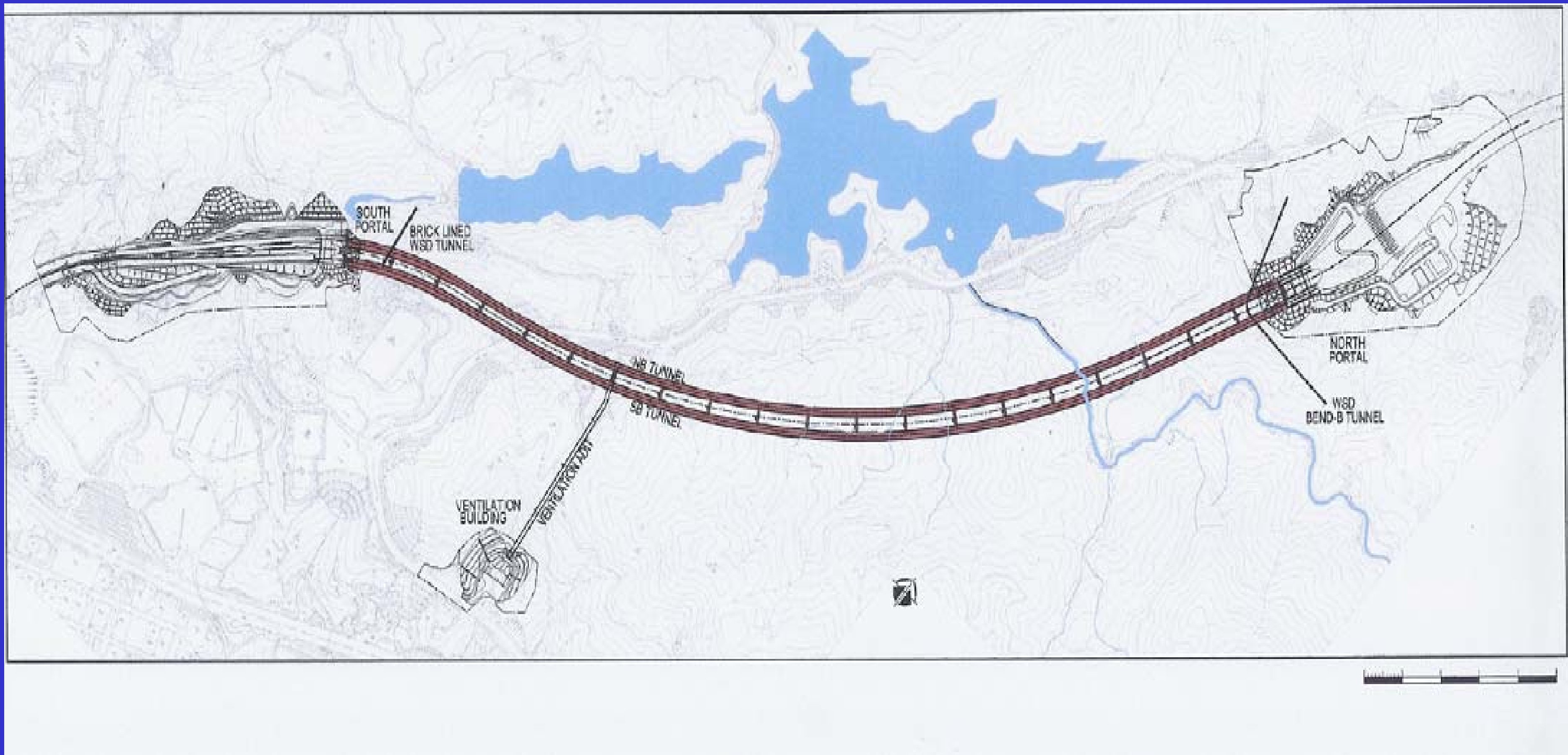
Risk Assessment and Management for the Eagles Nest Tunnels

- Project Overview
- Key Risks for the Construction of 2kms of Twin Bore Cavern Sized Tunnels
- Blasting Constraints for Tunnelling below Multiple WSD Facilities at Butterfly Valley
- Temporary Support Systems
- Prediction and Management of Water Inflows Close to Kowloon Group of Reservoirs
- Risk Assessment and Management Plan in Accordance with the New Code of Practice for Tunnelling
- Minimising Risks for Rock Tunnelling

Route 8 Eagles Nest tunnels – Leighton Kumagai JV

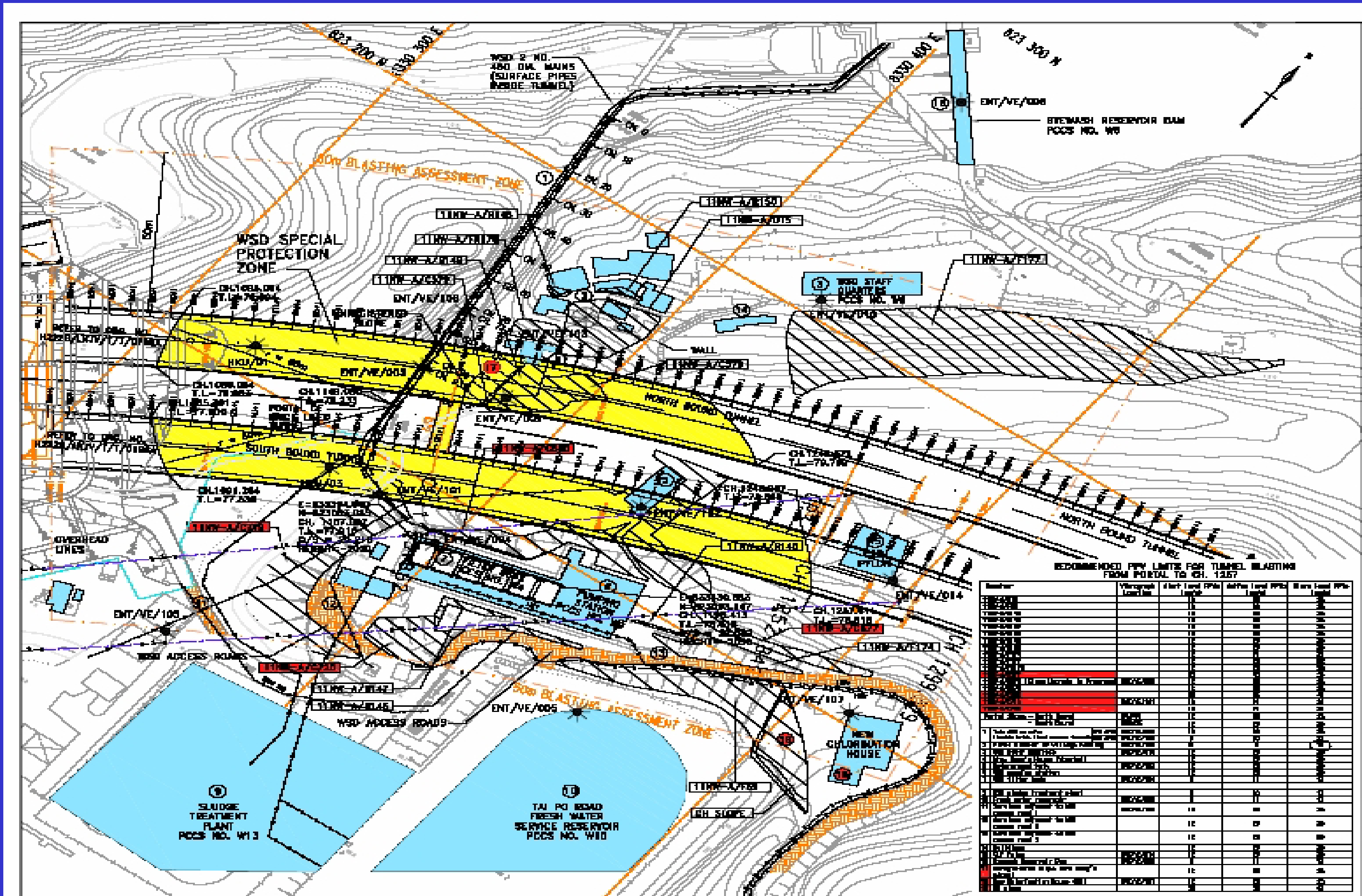


View from North Portal along route towards Lai Chi Kok

View along route from South Portal at Butterfly Valley

View of Southern Works and Ventilation Adit

Blasting Constraints at Butterfly Valley South Portal



Construction Issues for twin 16 – 18m span tunnels for Eagles Nest Tunnels

Rock Classification for Selection and Design of Temporary Support Systems

NORWEIGN GEOTECHNICAL INSTITUTE'S (NGI) Q - SYSTEM

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

where

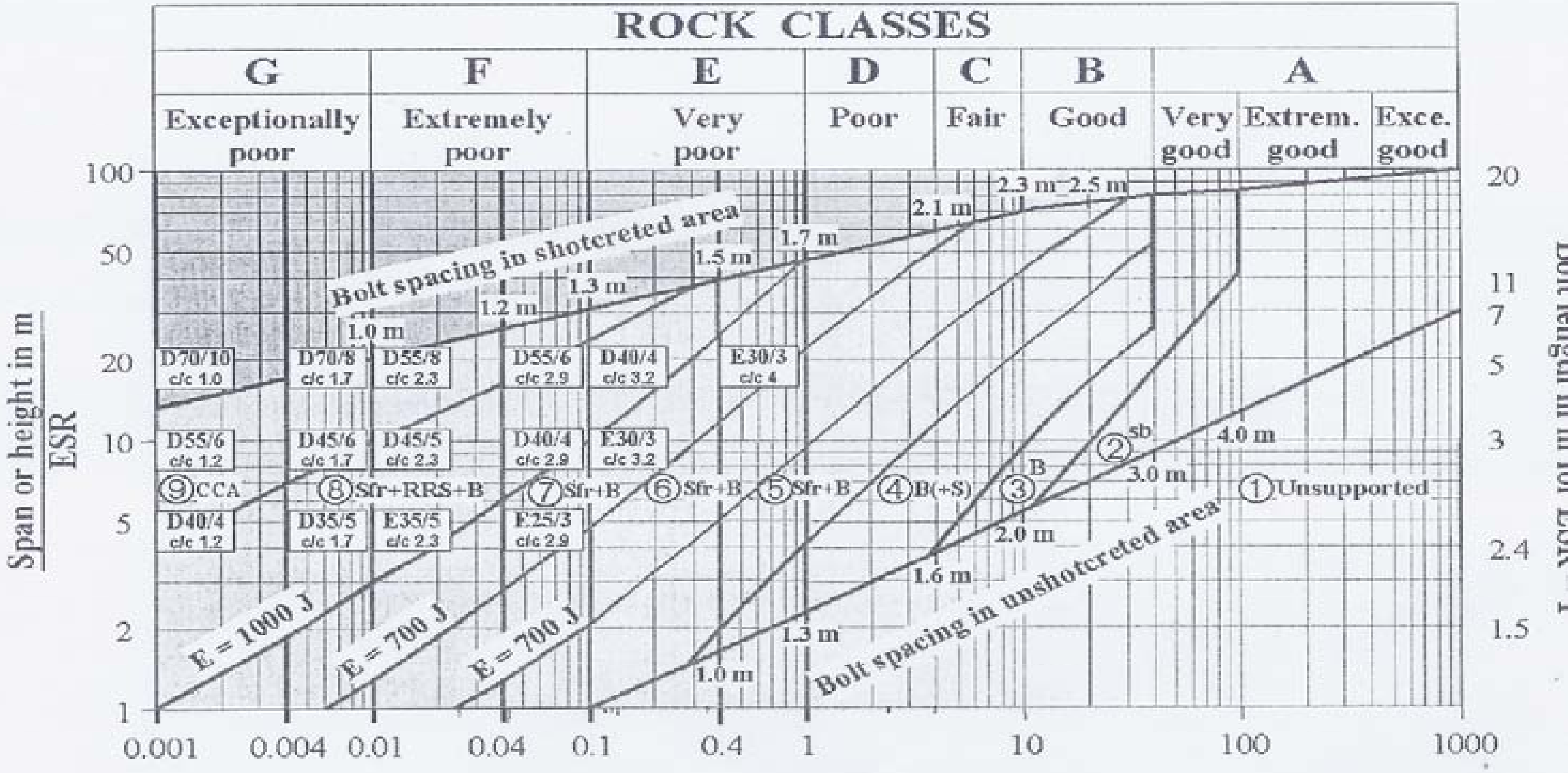
RQD	is the rock quality designation
Jn	is the joint set number
Jr	represents the joint roughness
Ja	represents the joint alteration
Jw	is a joint water reduction factor
SRF	is a stress reduction factor

Further $\frac{RQD}{Jn}$ represents rock block size

$\frac{Jr}{Ja}$ represents joint shear strength

And $\frac{Jw}{SRF}$ represents active stress

Selection of Temporary Supports using Q system



Rock mass quality $Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$

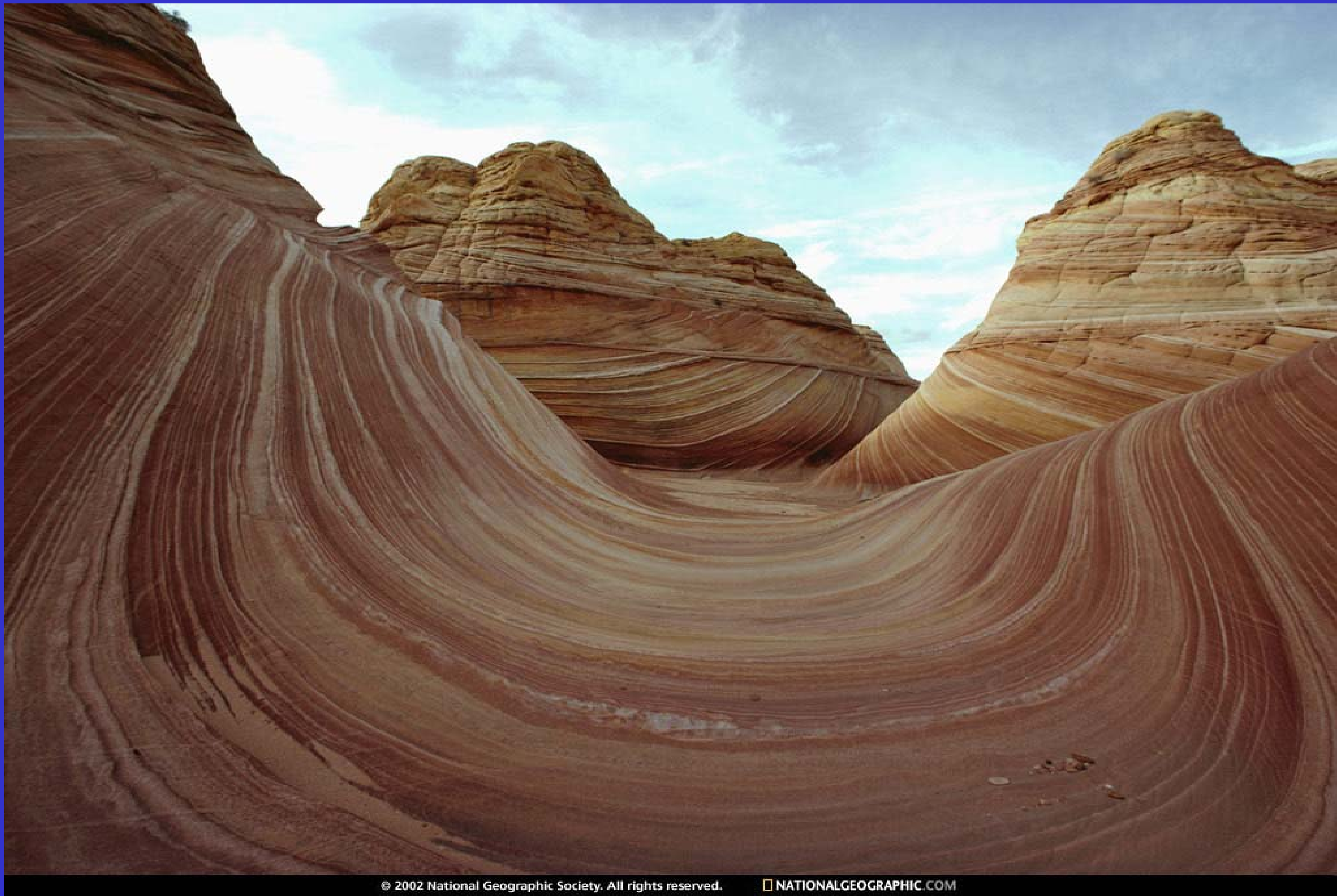
REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot bolting, **sb**
3) Systematic bolting, **B**
4) Systematic bolting, (and unreinforced shotcrete, 4-10 cm), **B(+S)**
5) Fibre reinforced shotcrete and bolting, 5-9 cm, **Sfr+B**
6) Fibre reinforced shotcrete and bolting, 9-12 cm, **Sfr+B**
7) Fibre reinforced shotcrete and bolting, 12-15 cm, **Sfr+B**
8) Fibre reinforced shotcrete > 15 cm + reinforced ribs of shotcrete and bolting, **Sfr+RRS+B**
9) Cast concrete lining, **CCA**

e) Energy absorbtion in fibre reinforced shotcrete at 25 mm bending during plate testing

D45/6 c/c 1.7	= RRS with 6 reinforcement bars in double layer in 45 cm thick ribs with centre to centre (c/c) spacing 1.7 m. Each box corresponds to Q-values on the left hand side of the box. (See text for explanation)

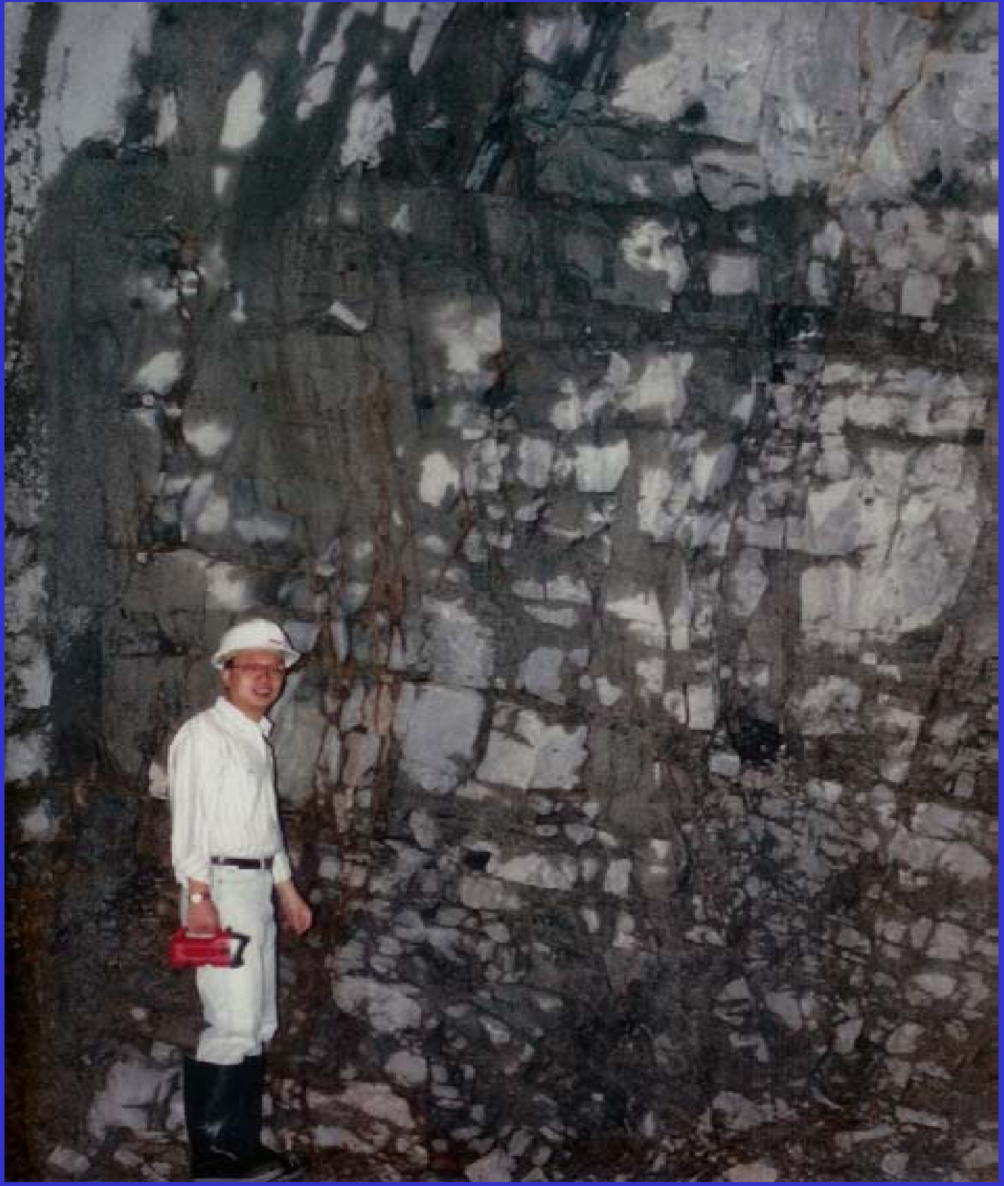
‘The problem is mathematics is black and white but the real world is grey’ – Albert Einstein



Key Issues for Classification of Rock Masses in Tunnelling

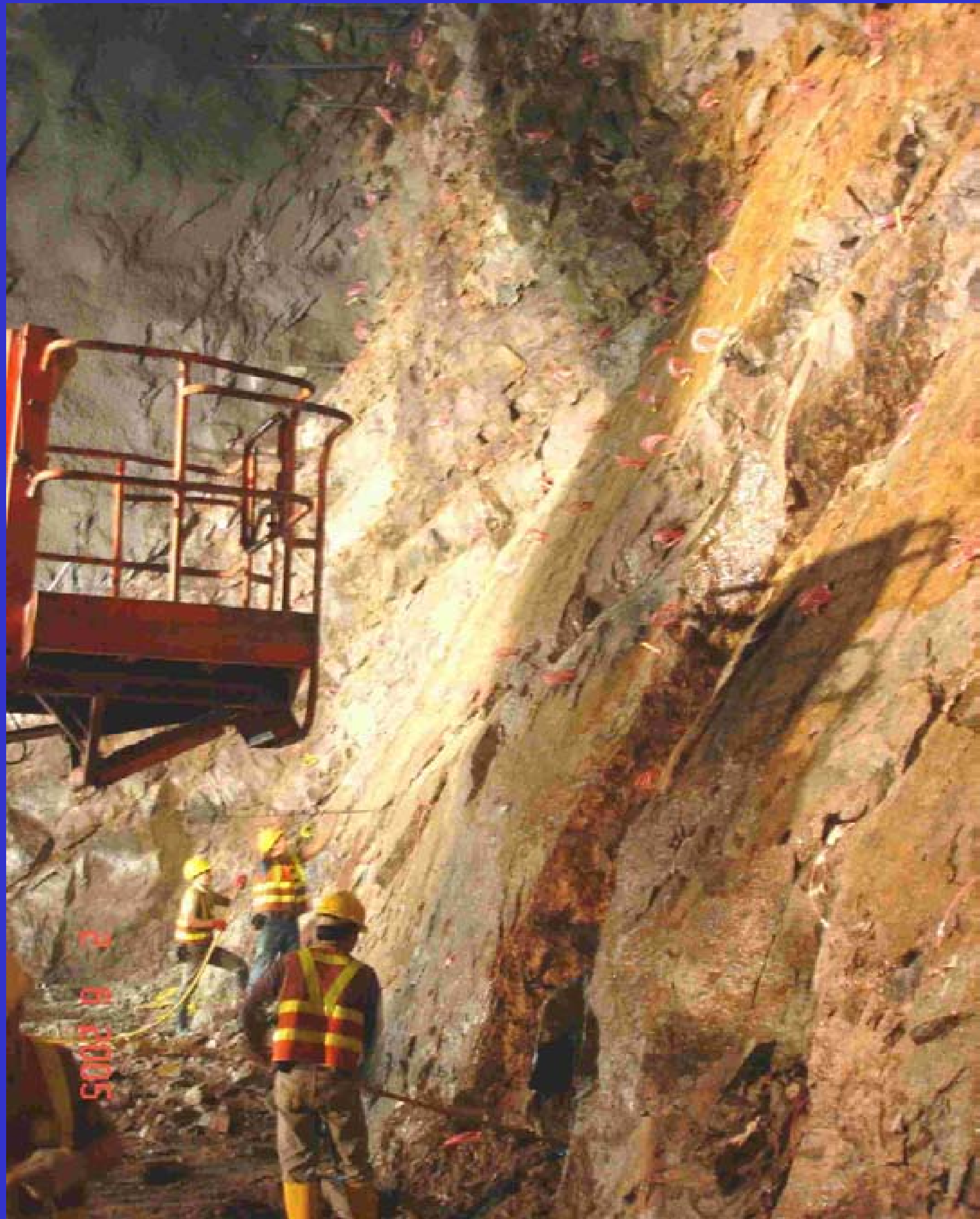
1) Variability of geology / temp supports

2) 3D - RQD assessment? 3) Proportion of blast fractures?

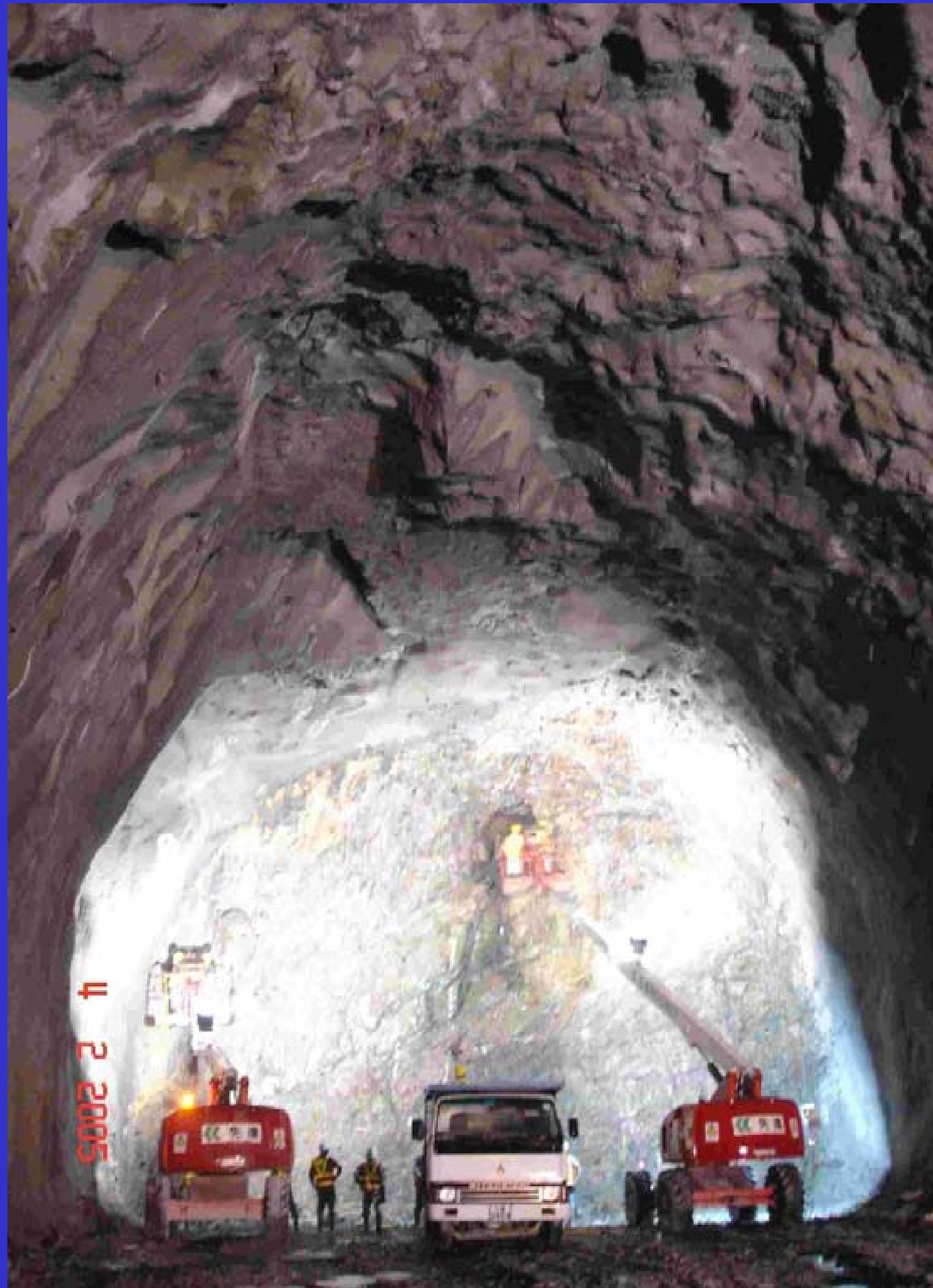


Are geotechnical engineers thinking for themselves - or simply following the pack ?

Adverse jointing affecting overbreak



Large overbreak due to adverse jointing



Excavation of Top Heading in Fault Zone at North Portal

Bench Excavation in Mixed Face Conditions at North Portal

Full Face Excavation with Low Rock Cover Steel Ribs, Fibre Shotcrete and Face Support at South Portal

Drilling at 8m Span Ventilation Adit

Charging drill holes at Ventilation Adit

Management and Prediction of Water Inflows in Rock Tunnelling

Grouting Spec for ENT – Comparison With SSDS Spec

For the Strategic Sewerage Disposal Scheme in Hong Kong the following grouting trigger levels were initially required by the client, The Drainage Services Department:

- 20 litres/minute through any probe hole ahead of the tunnel face

(R9 –9litres/minute for 24hrs from 25m long probe hole ahead of tunnel face)

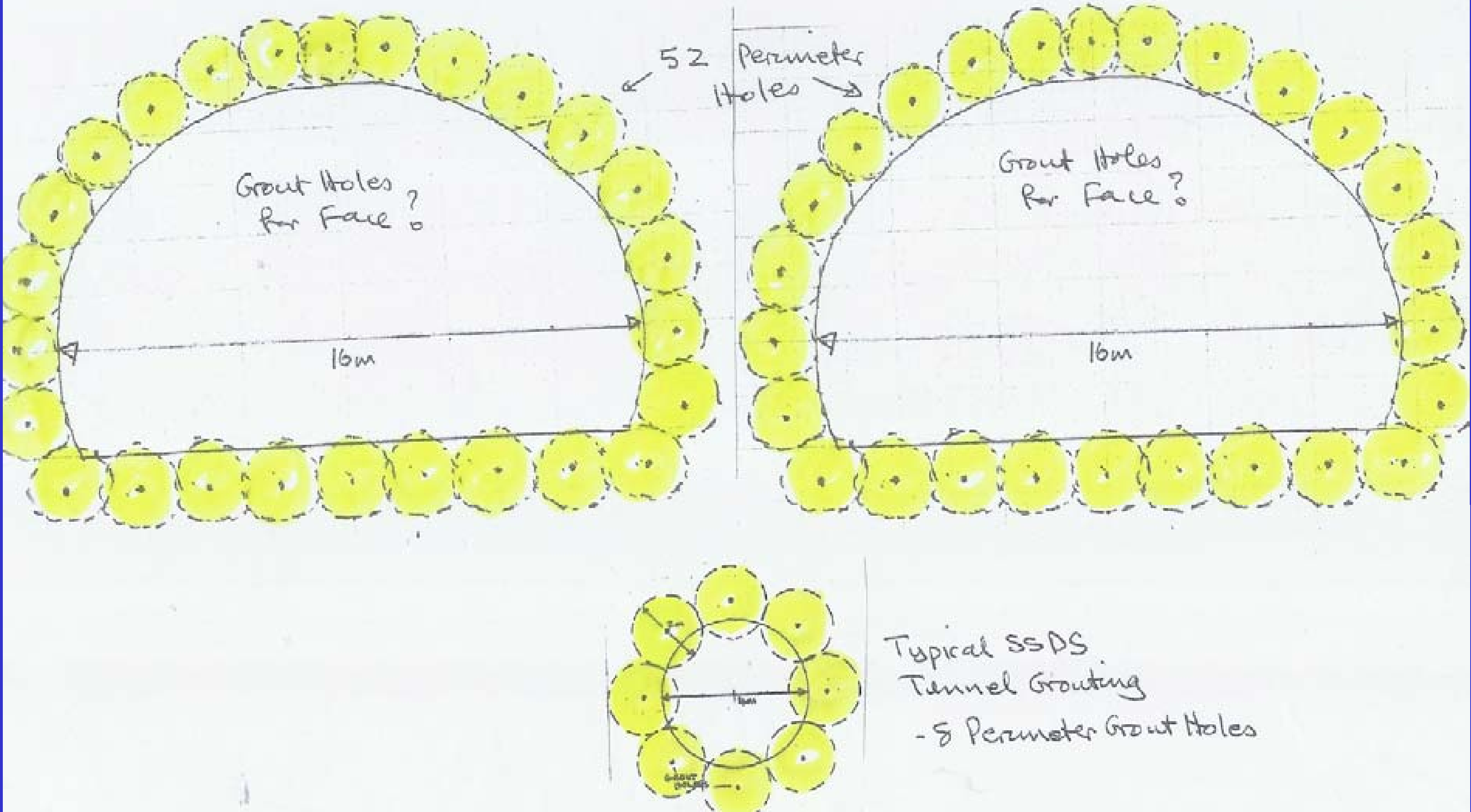
- 50 litres/minute at the tunnel face and within 25 metres of the face or over any 50 metre length of tunnel

(R9 – 36litres/minute for 24hrs within 25m of the tunnel face)

- 200 litres/minute over any 1000m length of tunnel

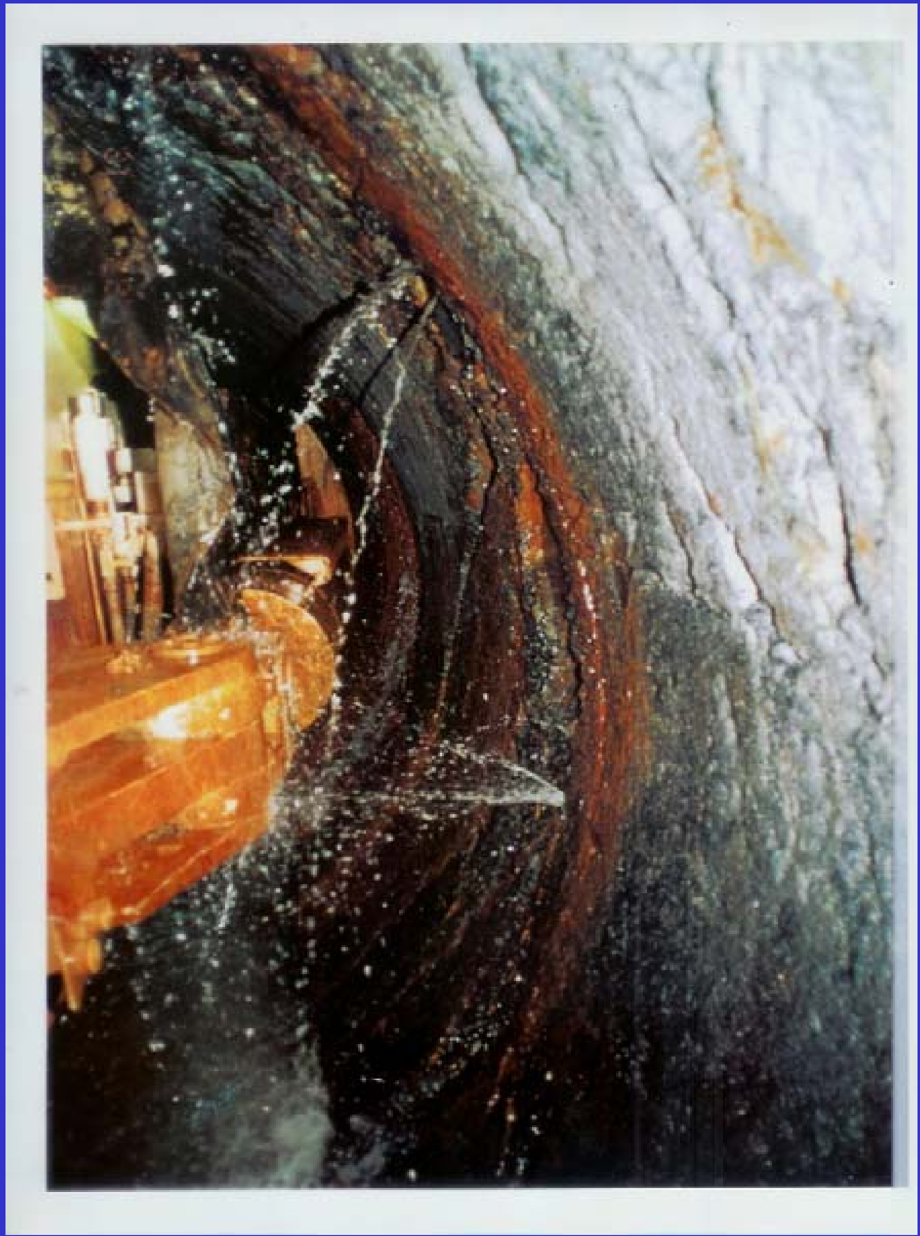
(R9 – 36litres/minute over any 100m length of tunnels. If not achieved then carry out post excavation grouting before tunnel lining allowed to be installed)

COMPARISON OF GROUTING REQUIREMENTS FOR SSDS TUNNELS AND TWIN THREE LANE HIGHWAY TUNNELS



Large inflows through individual open joints and shear zones

Disseminated water inflows at full hydrostatic head in local water inflows



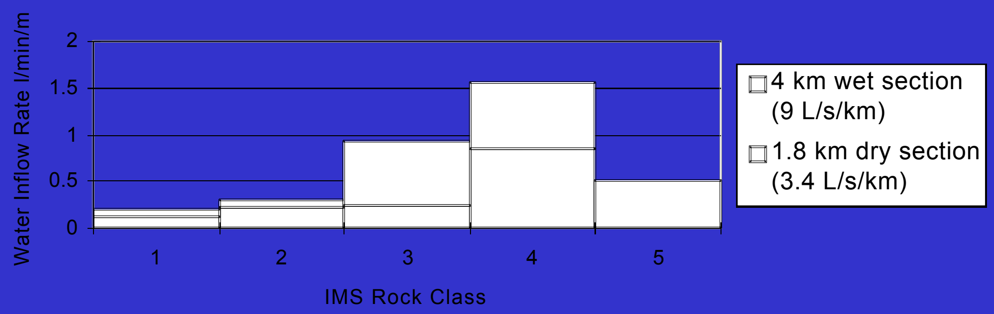
PREDICTION OF WATER INFLOWS INTO ROCK TUNNELS IN HONG KONG

Darcy equation: $Q = K \times a \times i$

Where:

Q = flow (m^3/day) **a = cross sectional area (m^2)**

K = hydraulic conductivity(m/d) **i = hydraulic gradient**



Estimated long term inflows from wet and dry section of land based tunnel

Calculated water inflow for IMS rock classes (l/min/m)

IMS Rock Class	High	Low
1	0.2	0.13
2	0.3	0.22
3	0.92	0.24
4	1.56	0.84
5	0.4	0.5

Prediction of Inflow Reduction Factor R = Sf.Hf.df

PREDICTION OF WATER INFLOWS INTO ROCK TUNNELS IN HONG KONG

METHOD OF PREDICTING INFLOW REDUCTION FACTOR (R)

Water Source Size Factor (Sf)		Head Factor (Hf) Head m/100 (m)		Horizontal Separation (df) Separation $df = 1 - \sqrt{\frac{dm}{400m}}$	
Source	Sf	Head m	Hf	0	1.0
Sea	1.0				
Major Valley/ Reservoir	0.85	>100	1.0	50	0.65
Large Valley/ Reservoir	0.7	100	1.0	100	0.5
Small River/ Reservoir	0.5	80	0.8	200	0.29
Stream	0.3	50	0.5	300	0.13
Ridge	0.1	20	0.2	400	0
				For d = 0 to 400m only	

Notes : R = Sf x Hf x df with R being dimensionless.

PREDICTION OF WATER INFLOWS INTO ROCK TUNNELS IN HONG KONG

Prediction of Initial (Ii) and Final Inflows (Fi)

$$Ii = R.IF \quad \& \quad Fi = R^2IF$$

IF VALUES FOR IMS ROCK CLASSES (l/min/m)

IMS Rock Class		1	2	3	4	5
IF values l/min/m	High	0.6	1.4	12.2	37	3.8
	Average	0.45	1.05	6.55	24	3.1
	Low	0.3	0.7	0.9	11	2.4

Prediction of Water Inflow Reduction Factors for Eagles Nest Tunnels

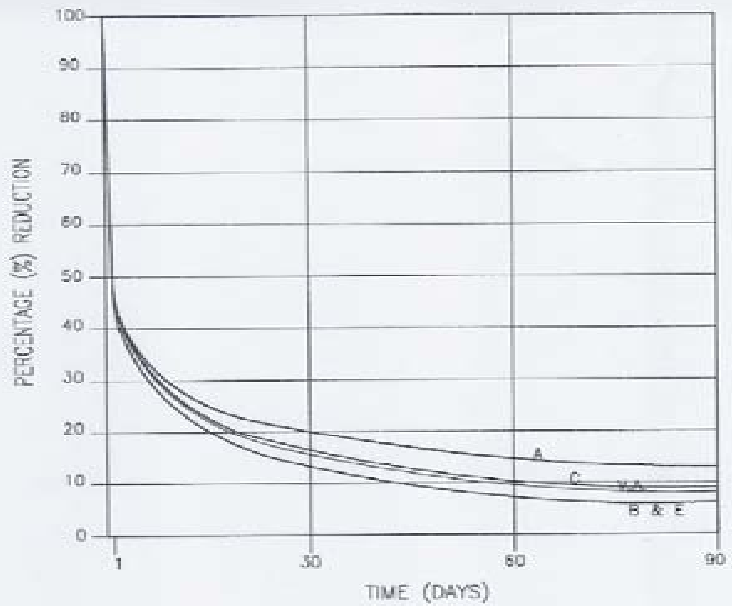


CHART SHOWING ESTIMATED % REDUCTION OF WATER INFLOWS WITH TIME FOR EACH INFLOW REGIME *

SECTION	TUNNEL CHAINAGE (m)	R	TIME (DAYS)			
			1	30	60	90
V.A.	VENTILATION ADIT	0.08	50	15.5	9.5	8
A	2232–2680	0.13	50	20	15	13
B	2680–3050	0.06	50	13	7	6
C	3050–3580	0.09	50	16	10	9
E	3580–4236	0.06	50	13	7	6

*After McFeat-Smith et al (1998)

IMS Tunnel Consultancy Limited

HIGHWAYS DEPARTMENT
Major Works Project Management Office

LEIGHTON–KUMAGAI JV

ROUTE 9 - EAGLE'S NEST TUNNEL AND ASSOCIATED WORKS
ESTIMATED WATER INFLOW REDUCTION (R%) WITH TIME

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GUIDE TO GROUND TREATMENT
FOR PRE-GROUTING OF ROCK TUNNELS

Rock mass classification		IMS Rock Class	Grouting required	Grout material
1.	**JOINTED ROCK**			
1.1	Massive, no joints	1	No grouting	N/A
1.2	Very few joints; < 0.1 joints/m^3	1	Spot or targeted grouting	MFC, if joints >0.5mm; OPC
1.3	Few joints; < 1 joints/m^3, ≤2 joint sets	2	Limited to continuous	MFC
1.4	Jointed rock; <10joints/m^3, >2 joint sets	3	Continuous	MFC
1.5	Very jointed rock; ≥ 10 joints/m^3	4-5A	Continuous, closer spacing, in stages	MFC, UFC
2.	**FAULT ZONES**			
2.1	Zones with clay	5A-5B	Displace, wash out/replace, compact	OPC, MFC
2.2	Silty zones	5A-5B	Penetrate, very close spacing, in stages	UFC, Chemical
2.2	Sandy zones	5A-5B	Penetrate, close spacing, in stages	MFC, UFC
2.3	Gravel zones or sugar cube rock	5A-5B	Penetrate, quick set, in stages	OPC, MFC
2.5	Mixed material	5A-5B	Penetrate, displace, compact, replace, in stages, close spacing	OPC, MFC, UFC, Chemical
3.	**REGIONAL STRUCTURAL ZONE**	Depends of size of zone and composition. Often a combination of 1.5 and 2.5 above.		

Route 8 Eagles Nest tunnels –

Horizontal borehole drilling at North Portal as a risk mitigation measure at initiative of Leighton Kumagai JV

Route 8 Eagles Nest tunnels–
Contractual Issues and Risk Management

HK Government Conditions of Contract

- 13(1) - Contractor deemed to have inspected site, access and determined the nature of the ground
- 13(2) - No claims entertained for any misleading or insufficient information provided
- 50(1 xi) EOT for 'any special circumstance of any kind whatsoever'

No recognition that unforeseen ground conditions can be special circumstances and definitely no payment despite EOT awards!

Value of HK Government Conditions of Contract for tunnelling works?

In-depth argument Robert Ng

Government drainage boss John Collier replies to questions in Legco about the problem-plagued sewage disposal scheme

New Code of Practice for Tunnels

- Client responsible for sufficiency of site investigations
- Geotechnical data forms part of contract
- Geotechnical baseline conditions to be drawn up by Client or Tenderer
- Geotechnical baseline conditions and used for assessing unexpected geological conditions
- Risk assessment and management at all stages of development of project
- Continuous tracking and mitigation of risks through risk register
- Insurance cover may be suspended or cancelled in event of a breach of code requirements

Risk Management Plan – Contents

Risk Management Systems

Risk management systems ensure that:

- Risks are identified for all aspects of the project
- Identified risks are evaluated as a product of their "Frequency" and "Consequences"
- Risk mitigation plans are established and implemented for each risk
- Resources are focussed on the most significant risks
- Risk status is reviewed on a scheduled basis
- Risk management activities driven by senior management

Route 8 Eagles Nest tunnels– Risk Mitigation Measures

Route 8 Eagles Nest tunnels – Leighton Kumagai JV

Key Risks

- Twin 16.5m span tunnels in major inclined fault zone and mixed face conditions at north portal
- Twin 18m span tunnels with little or no rockhead cover and 5m fill and CDG cover to overlying stream at south portal
- Tunnels driven close and parallel to Tolo Fault system adversely affecting rock mass conditions
- Severe blasting constraints due to proximity of WSD facilities – programme and cost risks
- Severe access constraints for excavation and spoil removal – creating programme risks
- Watertightness specification similar to SSDS for large span highway tunnels – probing and grouting risks as per SSDS

Route 8 Eagles Nest Tunnels –

Risk Mitigation Measures

- Drilling of two long horizontal boreholes from either portal up to 1150m long for the following purposes:

  - advance data on rock mass / rock classification and temporary supports
  - advance data on water inflows
  - advance information on decay of water inflows with time
  - opportunity for advance grouting from horizontal borehole

- Quality risk assessment and management by joint venture throughout contract

- Partnering to ensure close co-operation between parties involved in contract

- High quality construction management team

- High quality engineering management team for on site design of temporary support systems, grouting advisory services, special blasting services, geological probing and mapping work

Risk Management Systems need to:-

- Ensure impartial identification and mitigation of risks particularly when such measures are expensive and time consuming

- To be developed further to provide a structured approach to the evaluation of the overall project risk on a universal basis for financing and insuring purposes.

Conclusion: Minimising Risks for Tunnelling Projects

- Reduce uncertainty and risk by investing in well targeted site investigations
- Planning - seek specialist advice and second opinions, particularly on risks, opportunities and programmes
- Encourage technical innovation and alternative designs/approaches from contractors
- Adopt a positive attitude towards partnering – focus on openness, co-operation and fair payment
- Ensure that real engineering risk assessment and management is implemented and driven by senior management
- Consider risk sharing and re-measurement contracts