CVEN 5768 Spring 2019

ARMA

ROCK MASS CLASSIFICATION AND GROUND SUPPORT

Adapted from Presentation by

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"ROCK MECHANICS FOR PRACTITIONERS"

August 4 – 7, 2003

Boulder, Colorado

Underground Excavations

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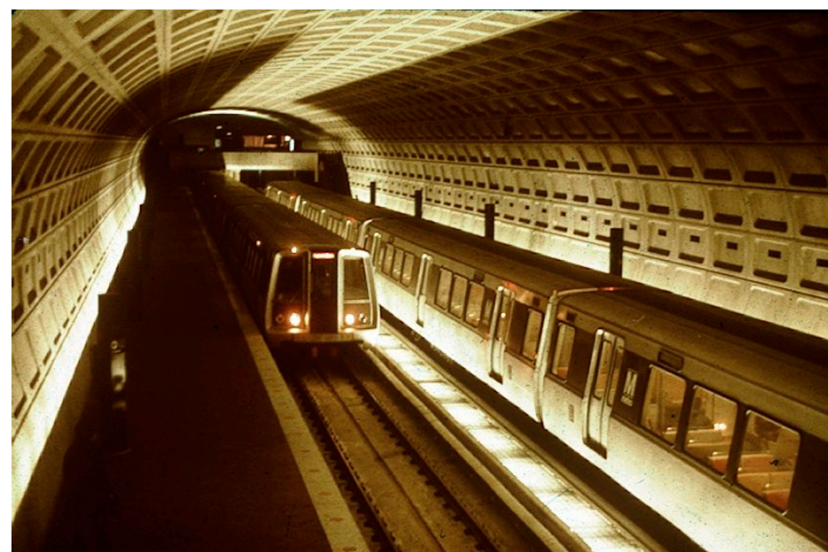
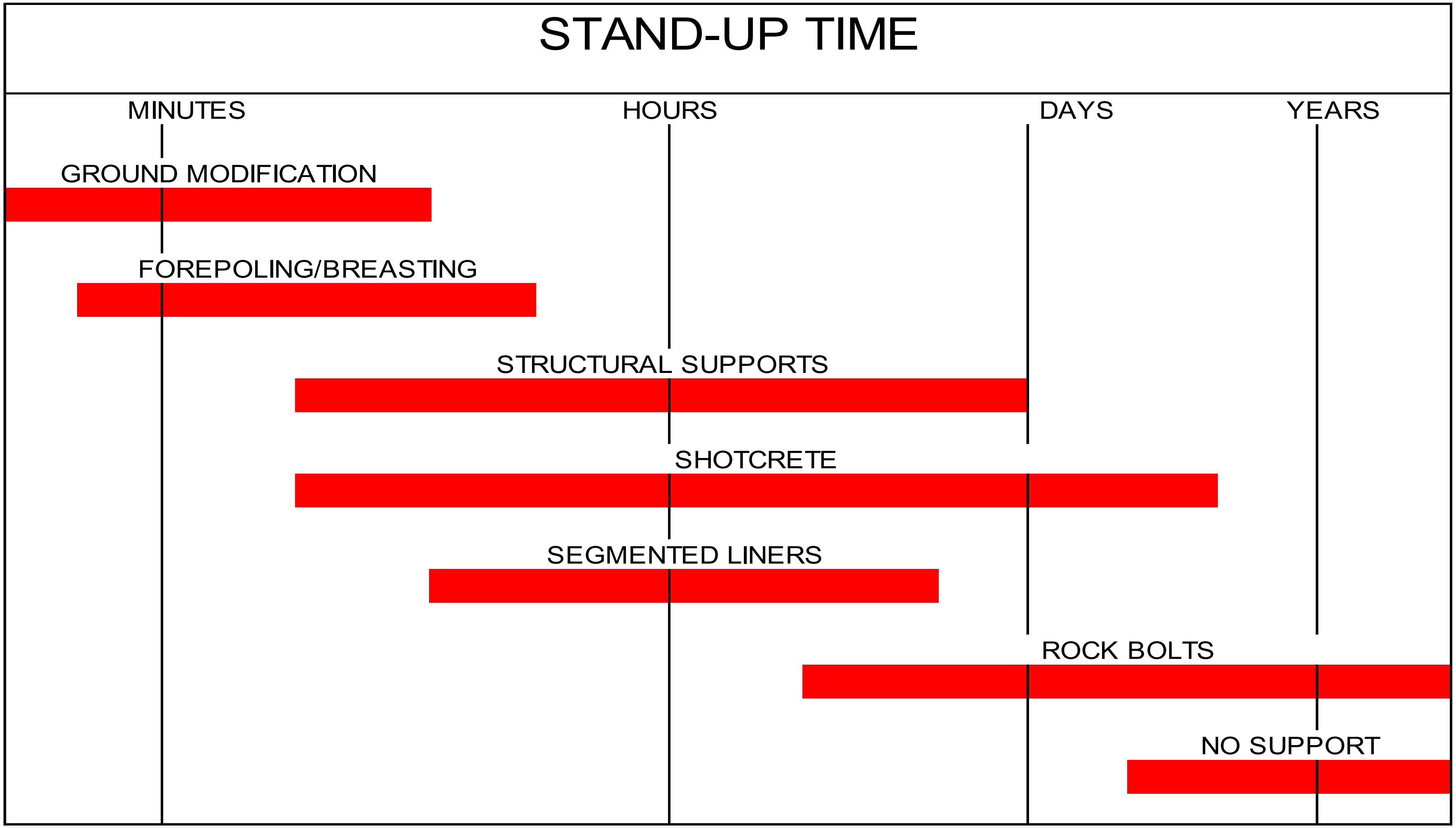



CHEYENNE MOUNTAIN COMPLEX
15

INITIAL GROUND SUPPORT



PRE-EXCAVATION GROUTING

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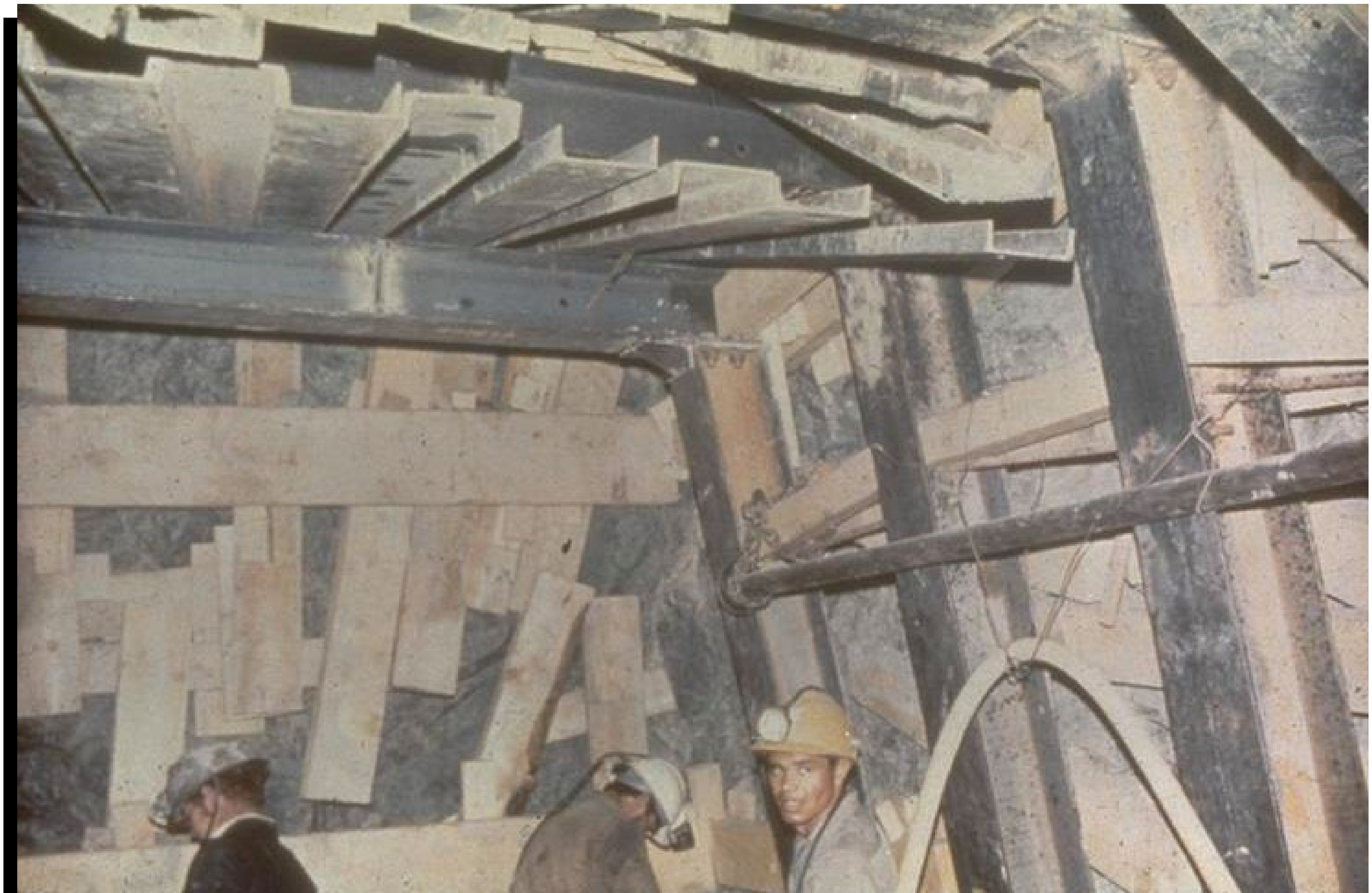
FOREPOLING AND BREASTING



RIBS AND BOARDS

STEEL SETS WITH INVERT STRUTS

SHOTCRETEING

ROBOTIC SHOTCRETE APPLICATION

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PRE-CAST CONCRETE SEGMENTS

STEEL LINER PLATE

ROBOTIC ROCK BOLT INSTALLER

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ROCK BOLTS, STRAPS & MESH

SMOOTHWALL DRILL AND BLAST

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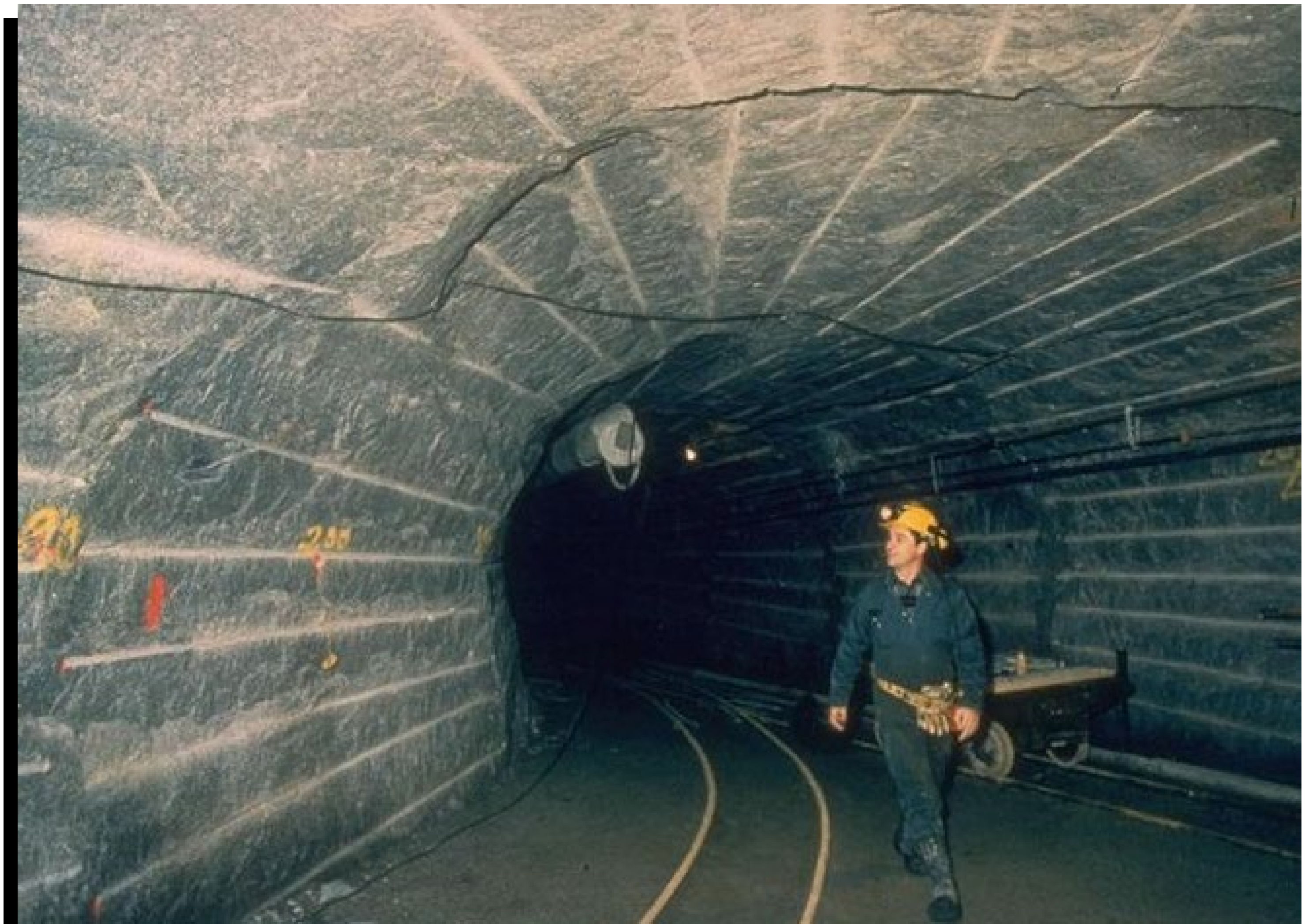

PERMANENT SUPPORT / FINAL LINING

- Precast Concrete Liners – A “One Pass” System
- Rock Bolts and Shotcrete
- Cast-In-Place Concrete Liners

PRE-CAST CONCRETE SEGMENTS

ROCK BOLTS AND SHOTCRETE AS PERMANENT SUPPORT

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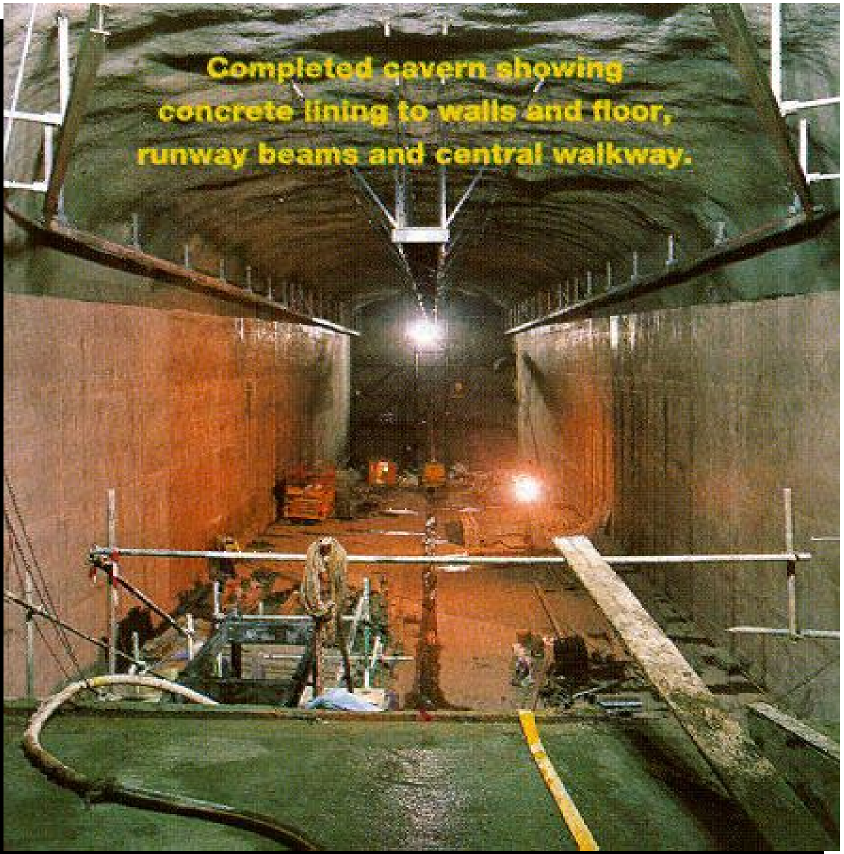
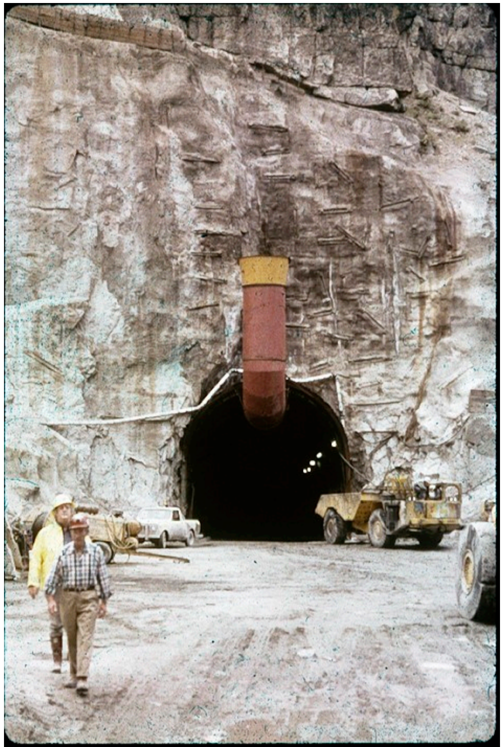


CAST-IN-PLACE CONCRETE SUPPORT

METHODS OF EXCAVATION

- Drill and Blast
  - Full face
  - Heading and Bench
  - Multi-drift Method
- Tunnel Boring Machines

DRILL AND BLAST TUNNEL



WORLDS LARGEST CONSTRUCTED UNDERGROUND

9.5 m TBM

TBM TUNNEL IN MASSIVE LIMESTONE

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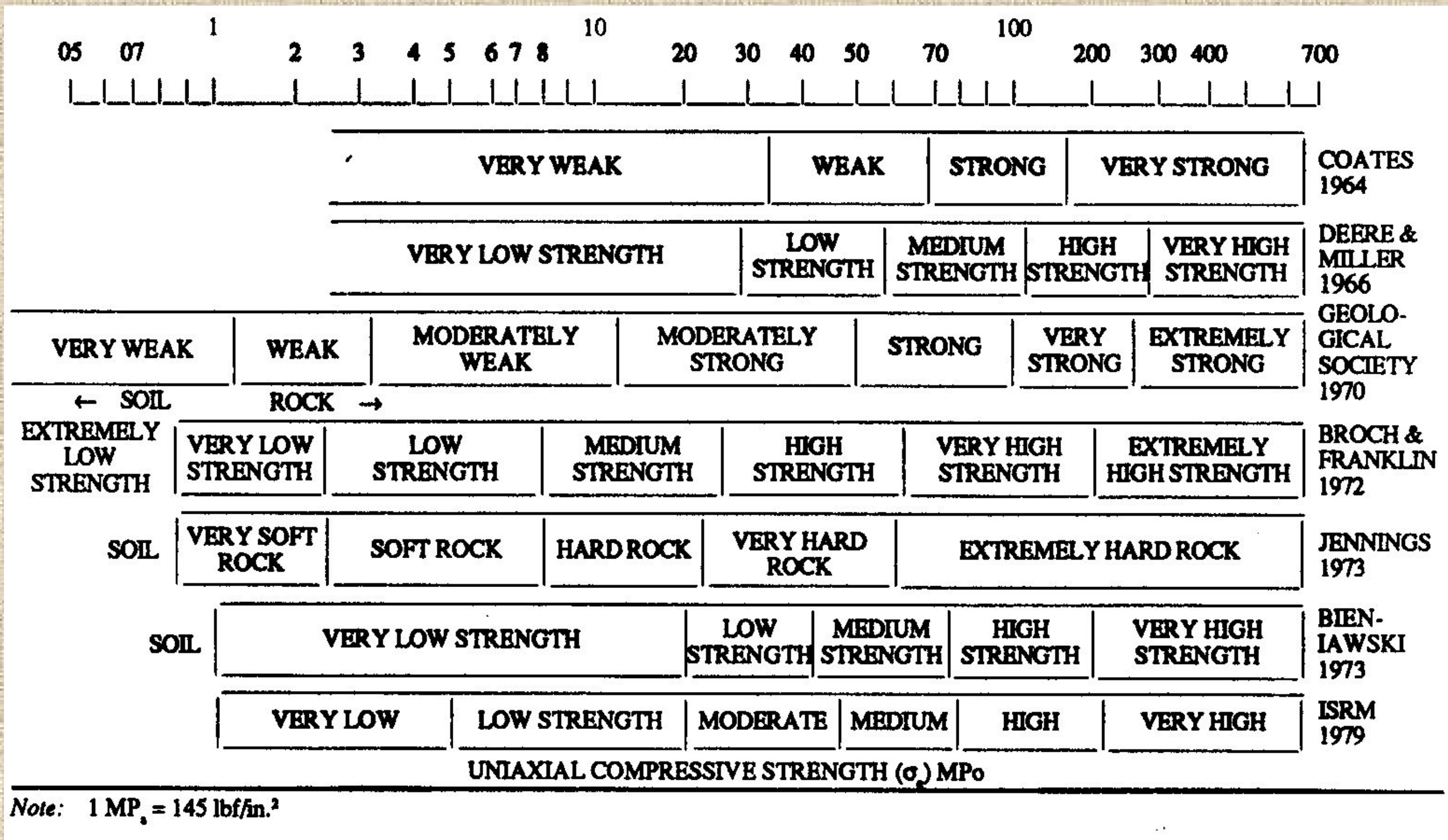
GEOLOGIC CLASSIFICATION

- Developed by petrographers for classical geologic descriptions
- Classify rock by modes of origin and mineral content
- "Interested in mechanical properties, not just names"
- Does not provide quantitative data for engineering purposes
- Inform us of potential weaknesses, for example
  - Sheet silicates: talc, mica, chlorite, serpentine, all alert us to rocks with low shear strength parallel to direction of imposed loads
  - Weak or soluble rocks: montmorillonite, gypsum, shales, chalk

CLASSIFICATION OF ROCK MATERIAL BASED ON UNCONFINED COMPRESSIVE STRENGTH (STAPLEDON AND ISRM)

Term for Uniaxial Compressive Strength	Symbol	Strength (MPa)
Extremely Weak	EW	0.25 – 1
Very Weak	VW	1 – 5
Weak	W	5 – 25
Medium Strong	MS	25 – 50
Strong	S	50 – 100
Very Strong	VS	100 – 250
Extremely Strong	ES	>250

COMPARISON OF VARIOUS ROCK STRENGTH CLASSIFICATIONS (BIENIAWSKI, 1979 *IN* AFROUZ, 1992)



INTACT VERSUS ROCK MASS PROPERTIES

"The major limitation on intact rock classifications is that they cannot provide quantitative data for engineering design purposes, Therefore, their main value lies in enabling better identification and communication during discussions of intact rock properties." (Bieniawski, 1989)

ROCK MASS CLASSIFICATIONS

OBJECTIVES OF ROCK MASS CLASSIFICATIONS (BIENIAWSKI, 1989)

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- Identify the most significant parameters influencing the behavior of a rock mass
- Divide a rock mass into classes of similar behavior
- Provide a basis for understanding the characteristics of each rock class
- Provide a basis to compare one site to conditions and experience at another site
- Derive quantitative data and guidelines for engineering design
- Provide a common basis for communication between geologists and engineers

CLASSIFICATION ATTRIBUTES (BEINIAWSKI, 1984)

- Simple, easily remembered, and understandable
- Uses terms and terminology widely accepted by engineers and geologists
- Includes the most significant properties of the rock mass
- Based on measurable (and repeatable) field parameters using quick and inexpensive tests
- Weighs the relative importance of the parameters
- Provides quantitative data for the design of rock support

ROCK MASS CLASSIFICATIONS

Advantages:

- **Improves site investigations by providing a minimum required program**
- **A short cut to rock mass properties that are often difficult to assess**
- **Only a few basic parameters relating to geometry and mechanical condition of the rock mass are used**
- **Provides quantitative information for design**
- **Direct guidance for engineering design e.g. predicting support requirements in tunnels**

ROCK MASS CLASSIFICATIONS

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Advantages (continued):

- Simplicity of approach even when dealing with complex rock masses
- Comfort in using the classification system
- Fast results
- Adaptable to field conditions for confirmation of assumptions
- Better communication between all parties
- Better engineering judgment for the project

ROCK MASS CLASSIFICATIONS

Disadvantages:

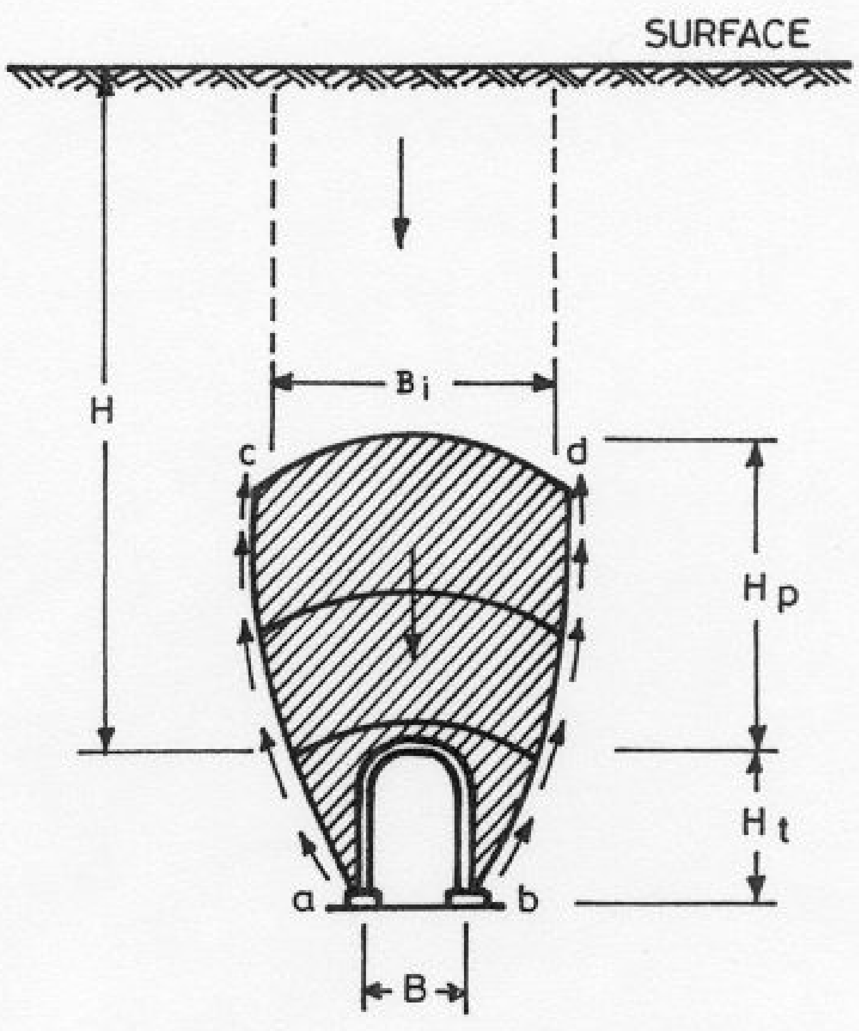
- **Still requires considerable experience for validation**
- **Absence of what may be critical parameters for certain projects, e.g. rock cover for pressure tunnels**
- **Anisotropy not fully considered**
- **False sense of security**

ROCK LOAD THEORY

TERZAGHI'S ROCK LOAD CLASSIFICATION

- "Introduction to Tunnel Geology" by Karl Terzaghi, *in,* Rock Tunneling with Steel Supports, Proctor and White, 1946
- The first practical classification system
- The "Tunnelman's Rock Mass Classification" for more than 50 years and still in use
- The first rational method of evaluating rock loads for designing steel sets
- Not totally applicable to modern ground support of rock bolts and shotcrete

ROCK LOAD THEORY, TERZAGHI, (1946)



DEFINITIONS OF ROCK CLASSES OF TERZAGHI'S ROCK LOAD THEORY (SINHA, 1989)

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Rock Class	Type of Rock	Definition
I.	Hard & intact	Rock is unweathered and contains neither joints nor hair cracks. The unconfined compressive strength is equal to or more than 100 MPa.
II.	Hard stratified and schistose	Rock is hard and layered, usually widely separated and may or may not have planes of weakness. Spalling is quite common.
III.	Massive moderately jointed	Joints are widely spaced and may or may not be cemented. Spalling may occur.
IV.	Moderately blocky and seamy	Blocks are about 1m in size. Rock may or may not be hard. The joints may or may not be healed.

DEFINITIONS OF ROCK CLASSES OF TERZAGHI'S ROCK LOAD THEORY (SINHA, 1989)

Rock Class	Type of Rock	Definition
V.	Very blocky and seamy	Closely spaced joints. Block size is less than 1m consisting of chemically intact rock fragments which are separated from each other and imperfectly interlocked. Vertical walls may require supports.
VI.	Completely crushed but chemically intact	Chemically intact rock having the character of a crusher run aggregate; no interlocking side pressure is expected on tunnel supports. The block size could be few centimeters to 30 cm.
VII.	Squeezing rock – moderate depth	Squeezing is a mechanical process in which the rock advances into the tunnel opening without perceptible increase in volume up to 1000m.
VIII.	Squeezing rock – great depth	The depth may be more than 150m. The maximum recommended tunnel depth is 1000m.
IX.	Swelling rock	Swelling is associated with volume change due to chemical change of the rock usually in presence of moisture or water. Some shales absorb moisture from air and swell. Rocks containing swelling minerals such as montmorillonite, illite, kaolinite and others can swell and exert heavy pressure on rock supports.

ROCK LOAD IN TUNNELS WITHIN VARIOUS ROCK CLASSES (TERZAGHI, 1946)

Rock Class	Rock Condition	Rock Load Factor, H_p	Remarks
I.	Hard and Intact	Zero	Light lining required only if spalling or popping occurs
II.	Hard stratified or schistose	0-0.5B	Light support mainly for protection against spalling.
III.	Massive moderately jointed	0-0.25B	No side pressure
IV.	Moderately blocky and seamy	0.25B-0.35 $(B+H_t)$	No side pressure
V.	Very blocky and seamy	(0.35-1.10) $(B+H_t)$	Little or no side pressure

ROCK LOAD IN TUNNELS WITHIN VARIOUS ROCK CLASSES (TERZAGHI, 1946)

ARMA

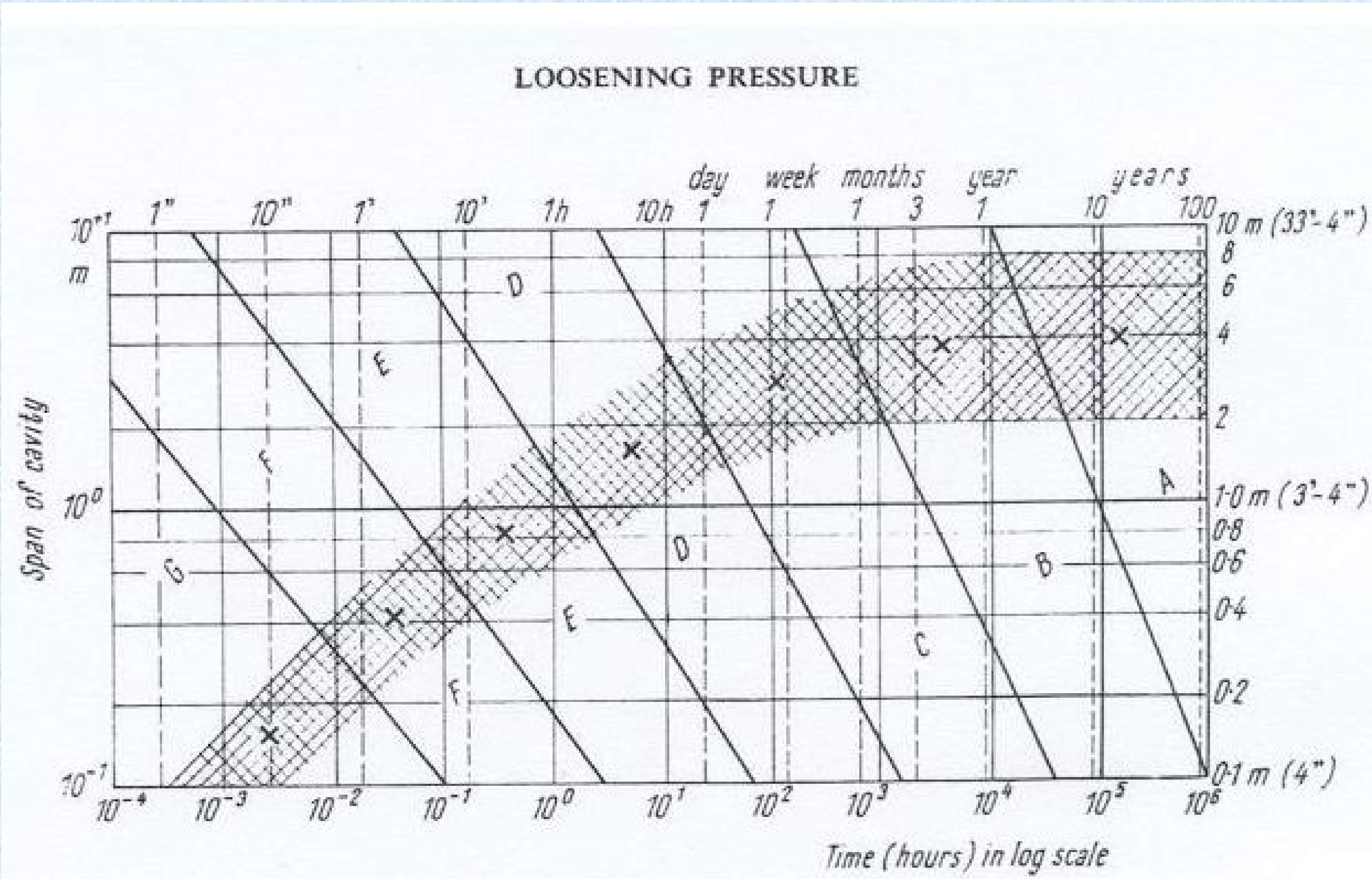
Rock Class	Rock Condition	Rock Load Factor, H_p	Remarks
VI.	Completely crushed	1.10 $(B+H_t)$	Considerable side pressure. Softening effects of seepage toward bottom of tunnel requires either continuous support for lower ends of ribs or circular ribs
VII.	Squeezing rock – moderate depth	(1.10-2,10) $(B+H_t)$	Heavy side pressure, invert struts required. Circular ribs are recommended
VIII.	Squeezing rock – great dpth	(2.10-4.50) $(B+H_t)$	-do-
IX.	Swelling rock	Up to 250 ft. irrespective of the value of $(B+H_t)$	Circular ribs are required. In extreme cases, use of yielding support recommended.

STAND-UP TIME

STAND-UP TIME (LAUFFER, 1958)

- Proposed by Lauffer in 1958 based on work by Stini, father of the Austrian School of tunneling and rock mechanics
- Assumed that ground stability is primarily based on structural defects
- “Stand-up Time” is dependent on rock quality and the span of the tunnel
- Realized that other factors could influence stand-up time, e.g.
  - orientation of tunnel axis
  - tunnel shape
  - excavation method
  - support method

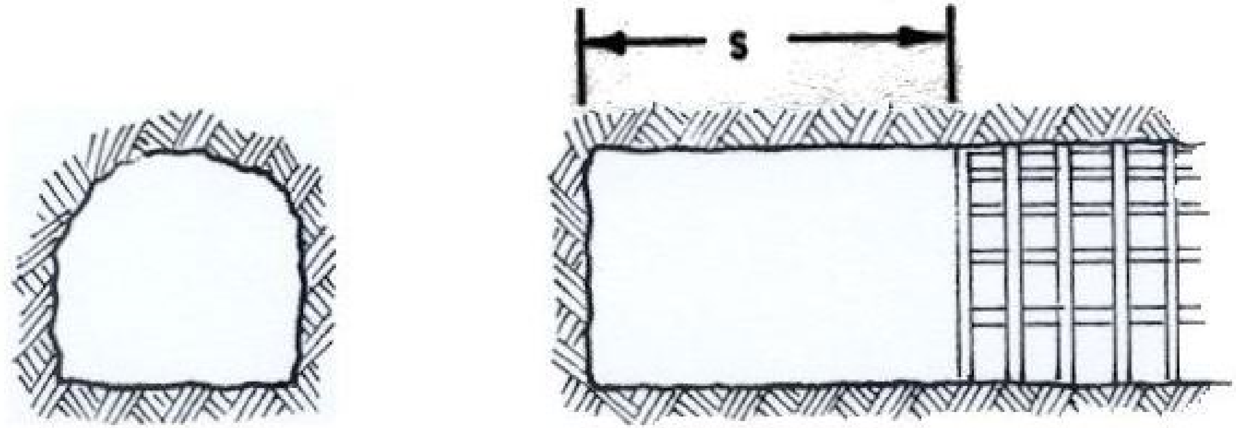
STAND-UP TIME (LAUFFER, 1958)



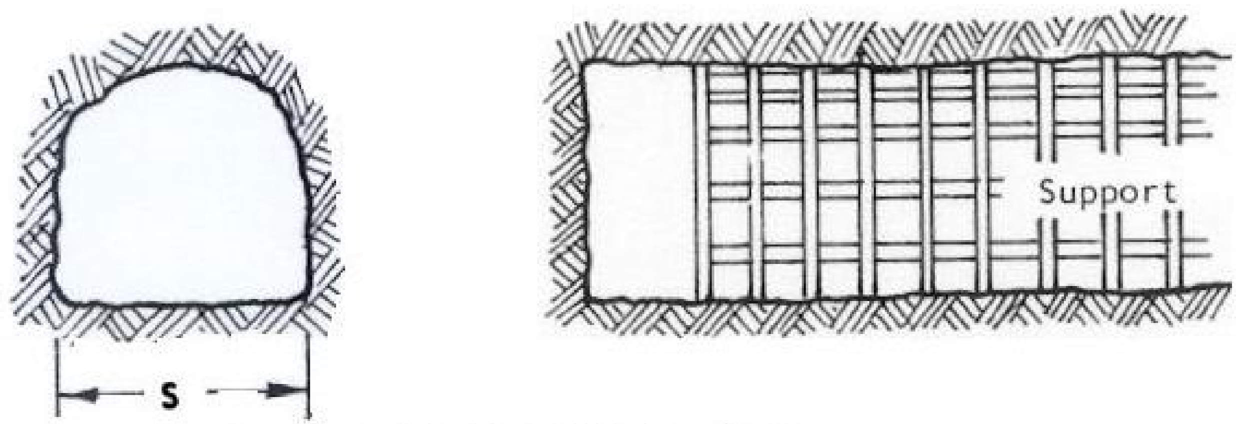
LAUFFER'S ROCK CLASSES

Rock class	Coordinated values between bridge action period - free span
A solid	20 years-4.0 m (13 ft)
B popping	6 months-4.0 m (13 ft)
C very popping	1 week-3.0 m (10 ft)
D fractured	5 hours-1.5 m (5 ft)
E very fractured	30 minutes-0.8 m (3 ft)
F pressive	2 minutes-0.4 m (1-4")
G very pressive	100 seconds-0.15 m (0-6")

LAUFFER'S DEFINITION OF SPAN

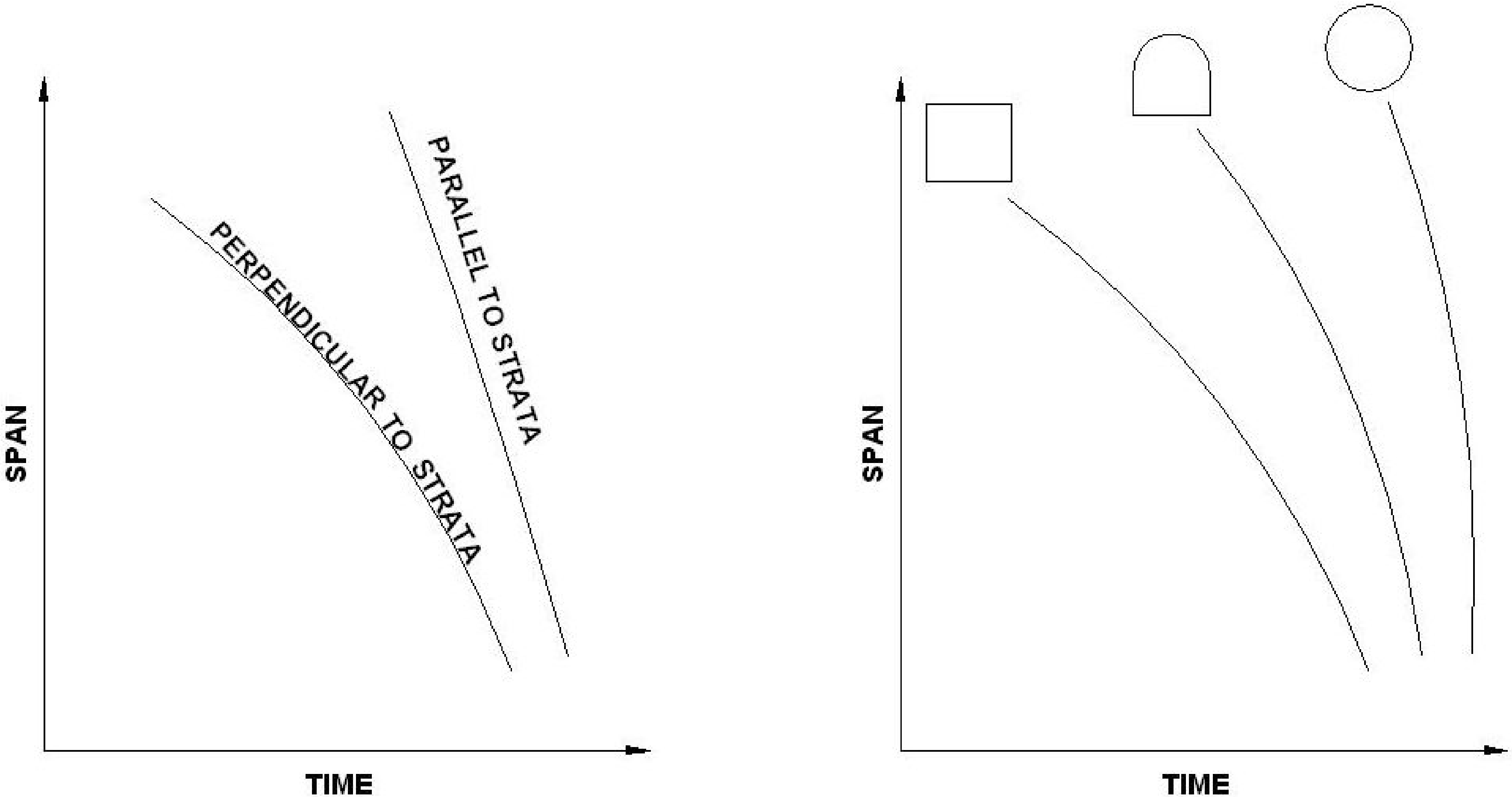


a. Support lagging behind face position.



b. Support placed close to face.

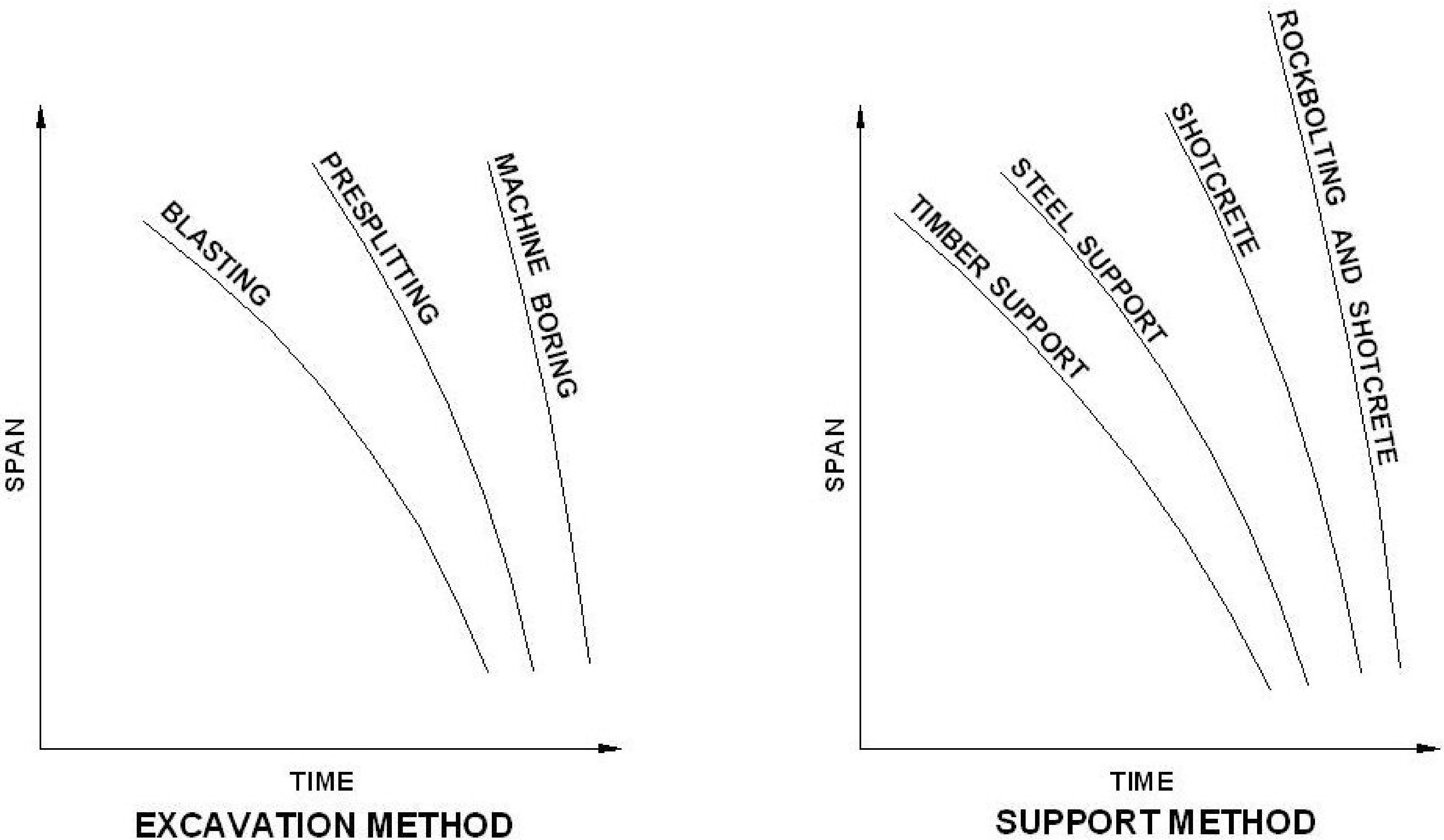
FACTORS INFLUENCING STAND-UP TIME, (AFTER LAUFFER, 1958 *IN* BIENIAWSKI, 1990)



ORIENTATION OF TUNNEL AXIS

FORM OF CROSS SECTION

FACTORS INFLUENCING STAND-UP TIME (AFTER LAUFFER, 1958 *IN* BIENIAWSKI, 1990)



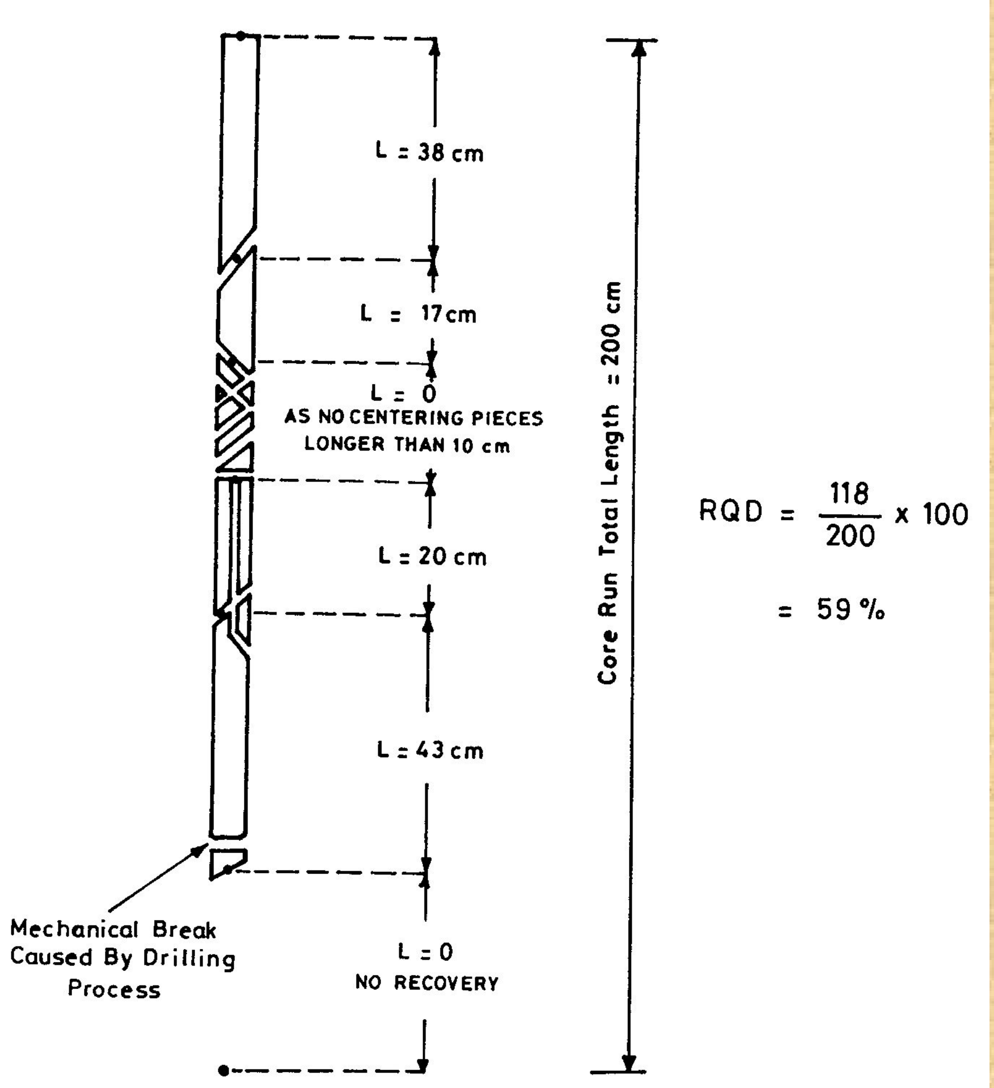
ROCK QUALITY DESIGNATION (RQD)

ROCK CORE EVALUATION

ROCK QUALITY DESIGNATION (RQD)

- Developed by Don U. Deere in 1964
- Significantly expanded by Deere, et al in 1967
- A useful index for determining rock quality from core recovery
- RQD= $\frac{\text{Length of "sound" core > 10 cm (4 in)}}{\text{Total Core Run Length}}$ X 100
- Core measured along centerline
- NX or NQ size core should be used

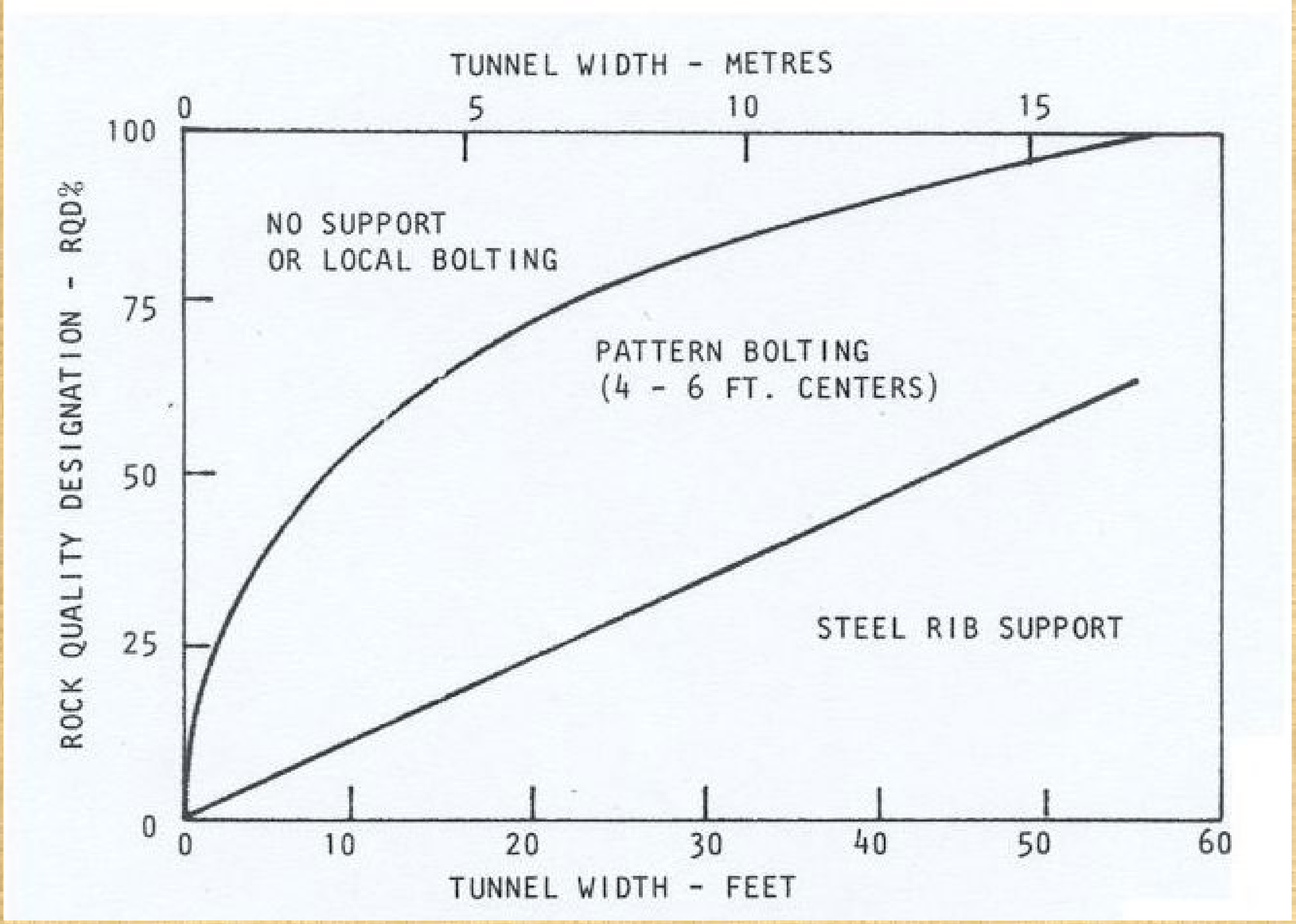
RQD MEASUREMENTS



CORRELATION BETWEEN RQD AND ROCK MASS QUALITY (DEERE, 1964)

RQD(%)	Rock Quality
<25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

PROPOSED USE OF RQD FOR ROCK SUPPORT (MERRITT, 1972)



GROUND SUPPORT BY RQD FOR 6m TO 12m DIAMETER (DEERE, ET AL, 1970)

Rock Quality	Construction Method	Steel Sets		Rock Bolt		Shotcrete		Additional Supports
		Weight of Steel Sets	Spacing	Spacing of Pattern Bolt	Additional Requirements	Total Thickness (cm)		
						Crown	Sides	
Excellent RQD > 90	Boring Machine	Light	None to Occasional	None to Occasional	Rare	None to Occasional	None	None
	Drilling & Blasting	Light	None to Occasional	None to Occasional	Rare	None to Occasional	None	None
Good RQD 75 to 90	Boring Machine	Light	Occasional to 1.5 to 1.8 m	Occasional to 1.5 to 1.8 m	Occasional mesh and straps	Local Application 5 to 7.5 cm	None	None
	Drilling & Blasting	Light	1.5 to 1.8 m	1.5 to 1.8 m	Occasional mesh and straps	Local Application 5 to 7.5 cm	None	None
Fair RQD 50 to 75	Boring Machine	Light to Medium	1.5 to 1.8 m	1.2 to 1.8 m	Mesh and straps as required	5 to 10 cm	None	Rock Bolts
	Drilling & Blasting	Light to Medium	1.2 to 1.5 m	0.9 to 1.5 m	Mesh and straps as required	10 cm or more	10 cm or more	Rock Bolts

GROUND SUPPORT BY RQD FOR 6m TO 12m DIAMETER (DEERE, ET AL, 1970)(Cont.)

Rock Quality	Construction Method	Steel Sets		Rock Bolt		Shotcrete		Additional Supports
		Weight of Steel Sets	Spacing	Spacing of Pattern Bolt	Additional Requirements	Total Thickness (cm)		
						Crown	Sides	
Poor RQD 25 to 50	Boring Machine	Medium Circular	0.6 to 1.2 m	0.9 to 1.5 m	Anchorage may be hart to obtain. Considerable mesh and straps required	10 to 15 cm	10 to 15 cm	Rockbolt as required (1.2 to 1.8 m center to center)
	Drilling & Blasting	Medium to Heavy circular	0.2 to 1.2 m	0..6 to 1.2 m	as above	15 cm or more	15 cm or more	as above
Very Poor RQD < 25	Boring Machine	Medium to Heavy circular	0.6 m	0.6 to 1.2 m	Anchorage may be impossible. 100 % mesh and straps required	15 cm or more on whole section		Medium sets as required
	Drilling & Blasting	Heavy circular	0.6 m	0.9 m	as above	15 cm or more on whole section		Medium sets as required
Very Poor Squeezing and Swelling	Both methods	Very Heavy circular	0.6 m	0.6 to 0.9 m	Anchorage may be impossible. 100 % mesh and straps required	15 cm or more on whole section		Heavy sets as required

LIMITATIONS ON RQD

- Does not account for the existence, thickness and strength characteristics of joint coating or filling material
- Does not account for joint roughness or interlock
- Can be significantly influenced by angle of boring
- “Sound” rock can be very subjective
- Core may deteriorate between drilling and logging
- 100 mm core length may be arbitrary for some excavations, e.g.
  NORAD
  Icelandic Power Chamber
- What RQD <u>really</u> means

ROCK MASS RATING (RMR)

ROCK MASS RATING (RMR)

- Originally developed by Z.T. (Dick) Bieniawski in 1973
- Also called “Geomechanics Classification of Rock Masses”
- Incorrectly called the “CSIR rating” or “CSIR Classification”
- Currently based on 351 case histories
- Modified several times – must state reference
- “not the answer to all design problems”

RMR SYSTEM (GEOMECHANICS CLASSIFICATION)

Based on six geotechnical parameters:

- **Uniaxial compressive strength of rock**
- **Rock quality designation (RQD)**
- **Spacing of discontinuities**
- **Condition of discontinuities**
- **Groundwater conditions**
- **Orientation of discontinuities**

STRENGTH OF INTACT ROCK MATERIAL (BIENIAWSKI, 1979)

Qualitative Description	Compressive Strength (MPa)	Point Load Strength (MPa)	Rating
Exceptionally strong	>250	8	15
Very strong	100 – 250	4-8	12
Strong	50 – 100	2-4	7
Average	25 – 50	1-2	4
Weak	10 – 25	Use of Uniaxial compressive strength is preferred	2
Very weak	2 – 10	-do-	1
Extremely weak	1 – 2	-do-	0

Note: At compressive strength less than 0.6 Mpa, many rock material would be regarded as soil

DRILL CORE QUALITY – RQD (BIENIAWSKI, 1979)

Description	Rating
90 – 100 %	20
75 – 90 %	17
50 – 75 %	13
25 – 50 %	8
< 25%	3

SPACING OF DISCONTINUITIES (BIENIAWSKI, 1979)

Description	Spacing (m)	Rating
Very wide	>2	20
Wide	0.6 – 2	15
Moderate	0.2 – 0.6	10
Close	0.06 – 0.2	8
Very Close	<0.06	5

CONDITION OF DISCONTINUITIES (BIENIAWSKI, 1979)

Description	Rating
Very rough and unweathered	30
Rough and slightly weathered	25
Slightly rough and moderately to highly weathered	20
Slickensided wall rock surface or 1-5mm thick gouge or 1-5mm wide continuous discontinuity	10
5mm thick soft gouge, 5mm wide continuous discontinuity	0

GROUND WATER CONDITION (BIENIAWSKI, 1979)

Inflow per 10m tunnel Length (litre/min.)	none	<10	10.25	25-125	>125
Joint water pressure / major principal stress	0	0-0.1	0.1-0.2	0.2-0.5	>0.5
General description	completely dry	damp	wet	dripping	flowing
Rating	15	10	7	4	0

ADJUSTMENT FOR JOINT ORIENTATION (BIENIAWSKI, 1979)

Joint Orientation Assessment for	Very Favorable	Favorable	Fair	Unfavor-able	Very Un-favorable
Tunnels	0	-2	-5	-10	-12
Raft Foundation	0	-2	-7	-15	-25
Slopes	0	-5	-25	-50	-60

ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100-81	80-61	60-41	40-21	<20
Class no.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

MEANING OF ROCK MASS CLASSES (BIENIAWSKI, 1974)

Class no.	I	II	III	IV	V
Average stand-up time	20y for 15m span	1yr for 10m span	1wk for 5m span	10h for 2.5m span	30min for 1 m span
Cohesion of rock mass (kPa)	>400	300 – 400	200 – 300	100 – 200	<100
Friction angle of rock mass (deg)	>45	35 – 45	25 – 35	15 – 25	<15

DESIGN PARAMETERS & ENGINEERING PROPERTIES OF ROCK MASS (BIENIAWSKI, 1979 & BIS CODE)

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S. No.	Parameter/Properties of Rock Mass	Rock Mass Rating (Rock Class)				
		100-81(I)	80-61 (II)	60-41 (III)	40-21 (IV)	<20 (V)
1.	Classification of rock mass	Very good	Good	Fair	Poor	Very poor
2.	Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hrs. for 2.5 m span	30 min. for 1 m span
3.	Cohesion of rock mass (MPa)	>0.4	0.3-0.4	0.2-0.3	0.1-0.2	<0.1
4.	Angle of internal friction	>45^{o}	35^{o}-45^{o}	25^{o}-35^{o}	15^{o}-25^{o}	15^{o}

GUIDELINES FOR EXCAVATION AND SUPPORT OF ROCK TUNNELS IN ACCORDANCE WITH THE ROCK MASS RATING SYSTEM (BIENIAWSKI, 1989)

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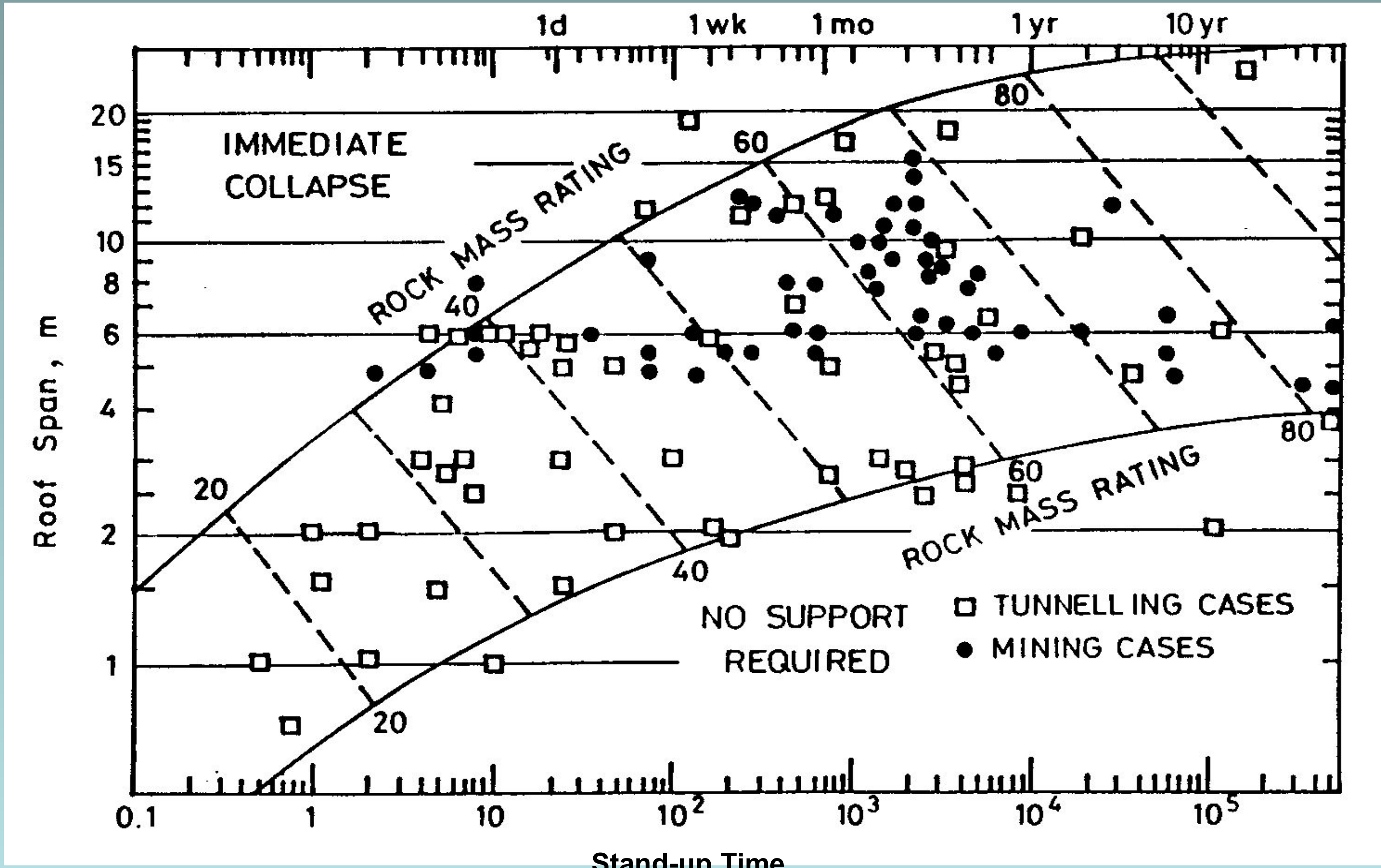
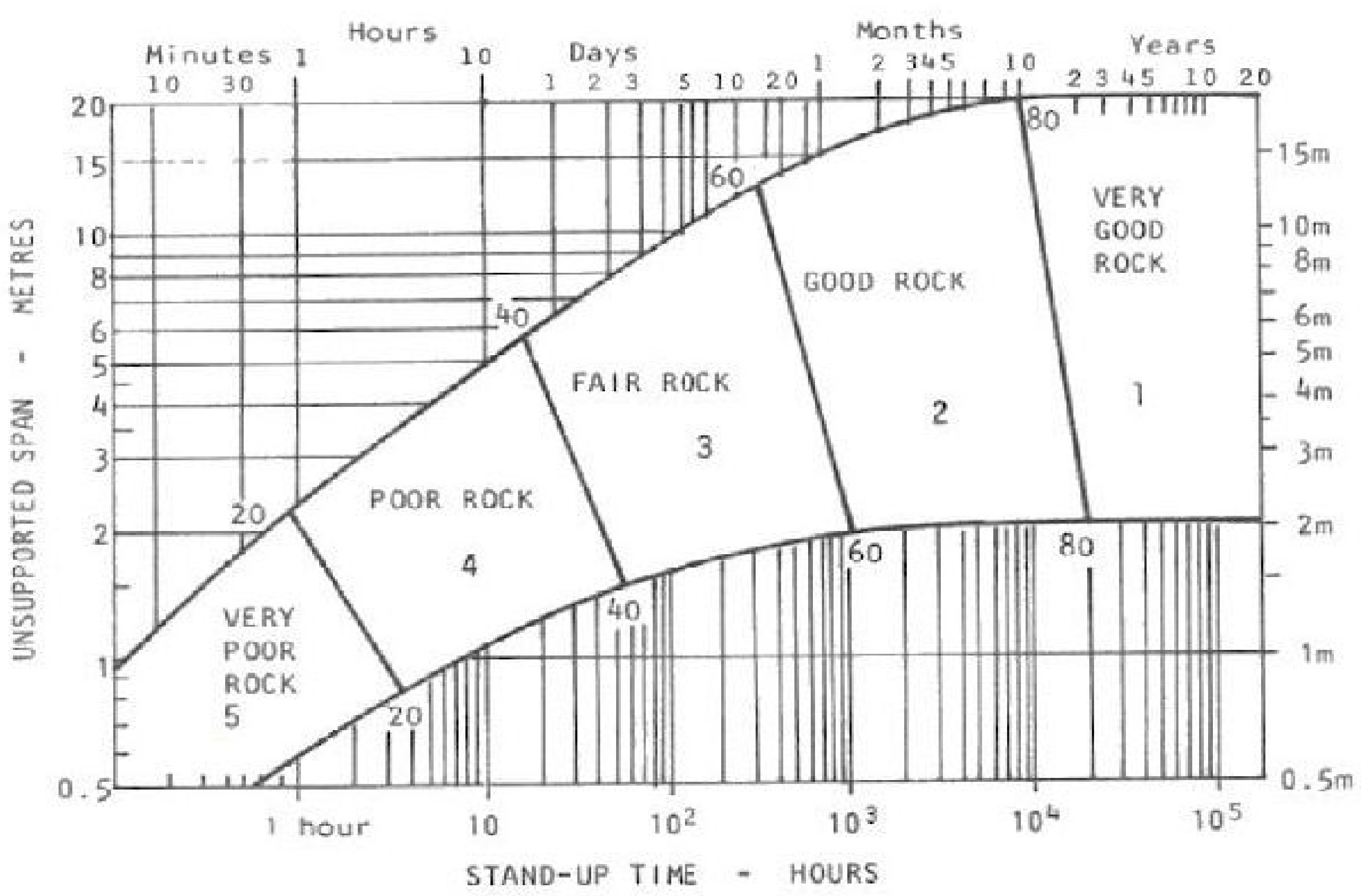
Rock Mass Class	Excavation	Supports: Rock bolts (20 mm dia fully Grouted)	Supports: Shotcrete	Supports: Steel sets
Very good rock RMR=81-100	Full face. 3m advance	Generally, no support required except for occasional spot bolting		
Good rock RMR=61-80	Full face.1.0-1.5m advance	Locally, bolts in crown 3m long, spaced 2.5m, with occasional wire mesh	50mm in crown where required	None
Fair rock RMR=41-60	Heading and bench. 1.5 - 3m advance in heading. Commence support after each blast	Systematic bolts 4m long Spaced 1.5-2m in crown and walls with wire mesh in crown	50-100 mm in crown and 30 mm in sides	None
Poor rock RMR21-40	Top heading and bench 1.0-1.5m in heading	Systematic bolts 4-5m long, spaced 1-1.5m w/ WWF	100-200mm in crown & 100mm on walls	Lt to med ribs spaced 1.5m as required
Very poor Rock RMR < 20	Mult. drifts 0,5-1.5 m advance on heading Shotcrete ASAP	Systematic bolts 5-6m long spaced 1-1.5m on crown and walls w/ WWF. Bolt invert	150-200mm in crown, 150mm on walls, 50mm on face	Med to Hvy ribs @ 0.75m w/ steel lagging. Close invert

RMR APPLIED TO STAND-UP TIME (BIENIAWSKI, 1989)

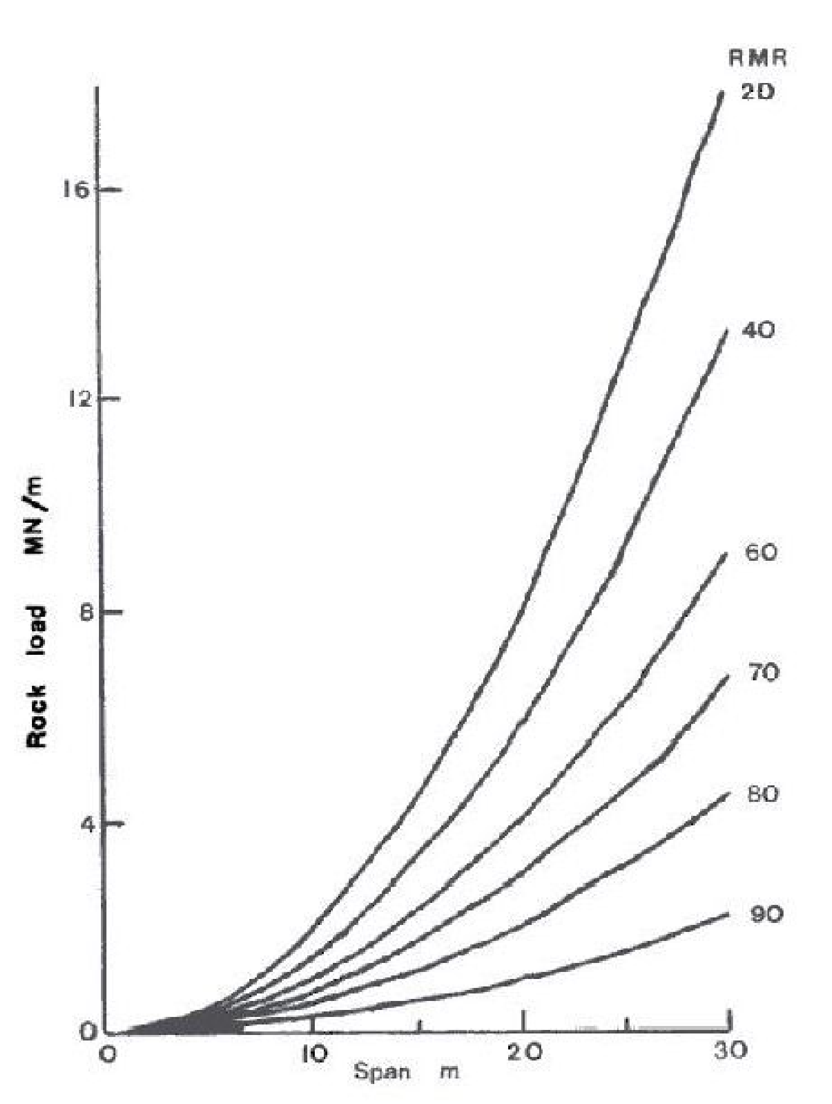


Stand-up Time

ROCK MASS RATING AND STAND-UP TIME (BIENIAWSKI, 1974)



CORRELATION BETWEEN SPAN, ROCK LOAD AND RMR, (BIENIAWSKI, 1989)

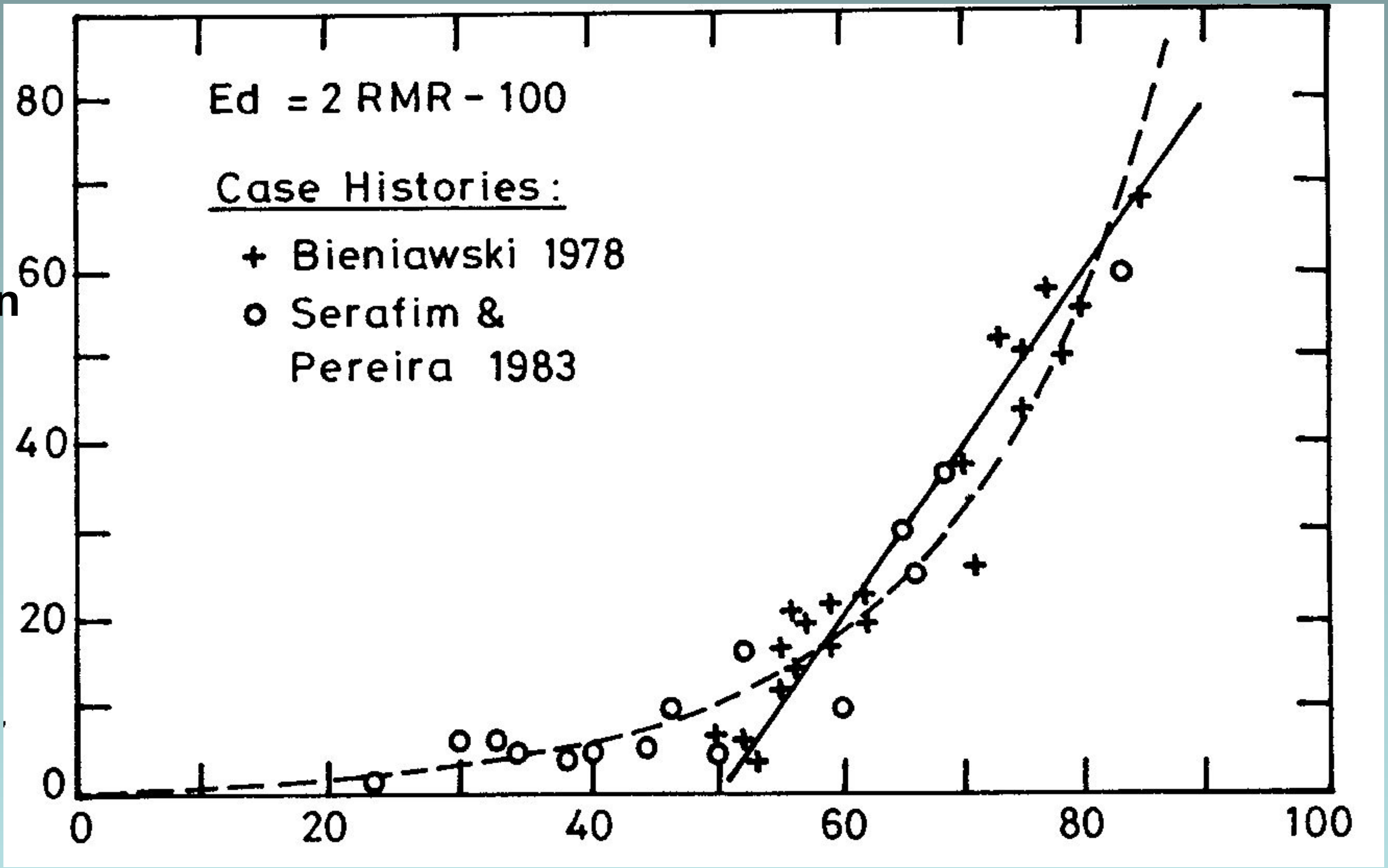


METHOD OF EXCAVATION BASED ON RMR (ABDULLATIF AND CRUDEN, 1983)

RMR Value	Excavation Method
< 30	Digging
31 - 60	Ripping
61 – 100	Blasting

CORRELATION BETWEEN Ed AND RMR (BIENIAWSKI, 1984)

Ed, in GPa



RMR

Q-SYSTEM

Q-SYSTEM OF ROCK MASS CLASSIFICATION

ARMA

Developed by Nick Barton, Lien and Lund, 1974

Also known as the Norwegian Geotechnical Institute (NGI) Classification

Originally based on 212 case histories; updated to now include more than 1500 case histories

Modified in 1993 by Barton and Grimstad to include ground support systems not available in 1974

"An engineering system facilitating the design of tunnel supports"

BASIS OF Q-SYSTEM

A numerical assessment of the rock mass quality based on seven parameters:

- RQD
- Number of joint sets
- Roughness of the most unfavorable joint or discontinuity
- Degree of alteration of filling along the weakest joint
- Water inflow
- Stress condition
- Equivalent dimension – a function of size and purpose of the excavation

Q-SYSTEM FORMULA

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The first six parameters are grouped into three quotients to give the overall rock mass quality Q:

$$Q = \left(\frac{RQD}{Jn}\right) \times \left(\frac{Jr}{Ja}\right) \times \left(\frac{Jw}{SRF}\right)$$

Where:

RQD = rock quality designation

Jn = joint set number

Jr = joint roughness number

Ja = joint alteration number

Jw = joint water reduction number

SRF = stress reduction factor

JOINT SET NUMBER J_n (BARTON ET AL, 1974)

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	Conditions	J_n
A.	Massive, none or few joints	0.5-1.0
B.	One joint set	2
C.	One joint set plus random	3
D.	Two joint sets	4
E.	Two joint sets plus random	6
F.	Three joint sets	9
G.	Three joint sets plus random	12
H.	Four or more joint sets, random, heavily jointed, "sugar cube", etc.	15
H.	Crushed rock, earth like	20

Note: (i) For intersections use $(3.0.J_n)$

(ii) For portals use $(2.0.J_n)$

JOINT ROUGHNESS NUMBER J_r (BARTON ET AL , 1974)

Conditions

		J_r
	(a) Rock wall contact and	
	(b) Rock wall contact before 10cm shear	
A.	**Discontinuous joint**	**4**
B.	**Rough or irregular, undulating**	**3**
C.	**Smooth, undulating**	**2.0**
D.	**Slickensided, undulating**	**1.5**
E.	**Rough or irregular, planar**	**1.5**
F.	**Smooth, planar**	**1.0**
G.	**Slickensided, planar**	**0.5**
	(c) No rock wall contact when sheared	
H.	**Zone containing clay minerals thick enough to prevent rock wall contact**	**1.0**
I.	**Sandy, gravelly, or crushed zone thick enough to prevent rock wall contact**	**1.0**

RATING DUE TO JOINT WATER (J_W)

ARMA

	Classification of joint water	J_w	Approx. water pressure (kg/cm^2)
A.	Dry excavations or minor inflow	1.0	<1
B.	Medium inflow or pressure	0.66	1-2.5
C.	Large inflow or high pressure with unfilled joints	0.5	2.5-10
D.	Large inflow or high pressure, outwash of joint fillings	0.33	2.5-10
E.	Exceptionally high inflow, decaying with time	0.2-0.1	>10
F.	Exceptionally high inflow, without noticeable decay	0.1-0.05	>10

JOINT ALTERATION NUMBER J_a
(BARTON ET AL, 1974)

ARMA

Conditions	Φ_r (degree)	j_r
A. Tightly healed, hard, non-softening, impermeable filling, i.e.,quartz or epidote	0.75	
B. Unaltered joint walls, surface staining only	25-35	1.0
C. Slightly altered joint walls, Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	25-30	2.0
D. Silty or sandy clay coatings, small clay fraction (non-softening)	20-25	3.0
E. Softening or low-friction clay mineral coatings, i.e., kaolinite, mica, chlorite, talc, gypsum, and graphite, etc.	8-16	4.0

JOINT ALTERATION NUMBER J_a (BARTON ET AL, 1974)

Conditions		Φ_r (degree)	J_a
	(b) Rock wall contact before 10 cm shear		
F.	Sandy particles, clay-free disintegrated rock	25-30	4.0
G.	Strongly over-consolidated, non-softening clay mineral fillings	16-24	6.0
H.	Medium or low over-consolidation, softening, clay mineral fillings	12-16	8.0
I.	Swelling clay fillings, i.e., montmorillonite	6-12	8-12

JOINT ALTERATION NUMBER Ja (BARTON ET AL, 1974)

Conditions	Φ_r (degree)	J_a
(c) No rock wall contact when sheared		
J. Zones or bands of disintegrated or crushed rock	**6-24**	**8-12**
L. Zones or bands of silty or sandy clay, small clay, fraction (non-softening)	**5**	
M. Thick continuous zones or bands of clay	**6-24**	**13-20**

Note: (i) Values of Φ_r are intended as an approximate guide to the mineralogical properties of the alteration products.

STRESS REDUCTION FACTOR, SRF (BARTON ET AL, 1974 AND GRIMSTAD AND BARTON, 1993)

ARMA

	Conditions	SRF
(a)	*Weakness zones intersecting excavation, which may cause loosening of rockmass when tunnel is excavated*	
A.	**Multiple occurrences of weakness zones containing clay or chemically disintegrated rock**	**10.0**
B.	**Single-weakness zones containing clay or chemically disintegrated rock (depth ≤50 m)**	**5.0**
C.	**Single-weakness zones containing clay or chemically disintegrated rock (depth >50m)**	**2.5**
D.	**Multiple-shear zones in competent rock (clay-free)**	**7.5**
E.	**Single shear zones in competent rock (clay-free) (depth ≤50m)**	**5.0**
F.	**Single-shear zones competent rock (clay-free) (depth of >50m)**	**2.5**
G.	**Loose open joints, heavily jointed or “sugar cube”, etc.**	**5.0**

STRESS REDUCTION FACTOR SRF (BARTON ET AL, 1974 AND GRIMSTAD AND BARTON, 1993)

	Conditions	SRF
(b)	*Competent rock, rock stress problems*	
H.	**Low stress, near surface open joints**	**2.5**
J.	**Medium stress, favorable stress condition**	**1.0**
K.	**High stress, very tight structure**	**0.5-2.0**
L.	**Moderate slabbing after >1 hr in massive rock**	**5-50**
M.	**Slabbing and rock burst after a few minutes, massive rock**	**50-200**
N.	**Heavy rock burst and immediate deformations, massive rock**	**200-400**

DESCRIPTION OF RANGES IN THE Q-SYSTEM

ARMA

0.001-0.01	Exceptionally poor
0.01-0.1	Extremely poor
0.1-1	Very poor
1-4	Poor
4-10	Fair
10-40	Good
40-100	Very good
100-400	Extremely good
400-1000	Exceptionally good

EQUIVALENT DIMENSION, D_e (BARTON ET AL, 1974)

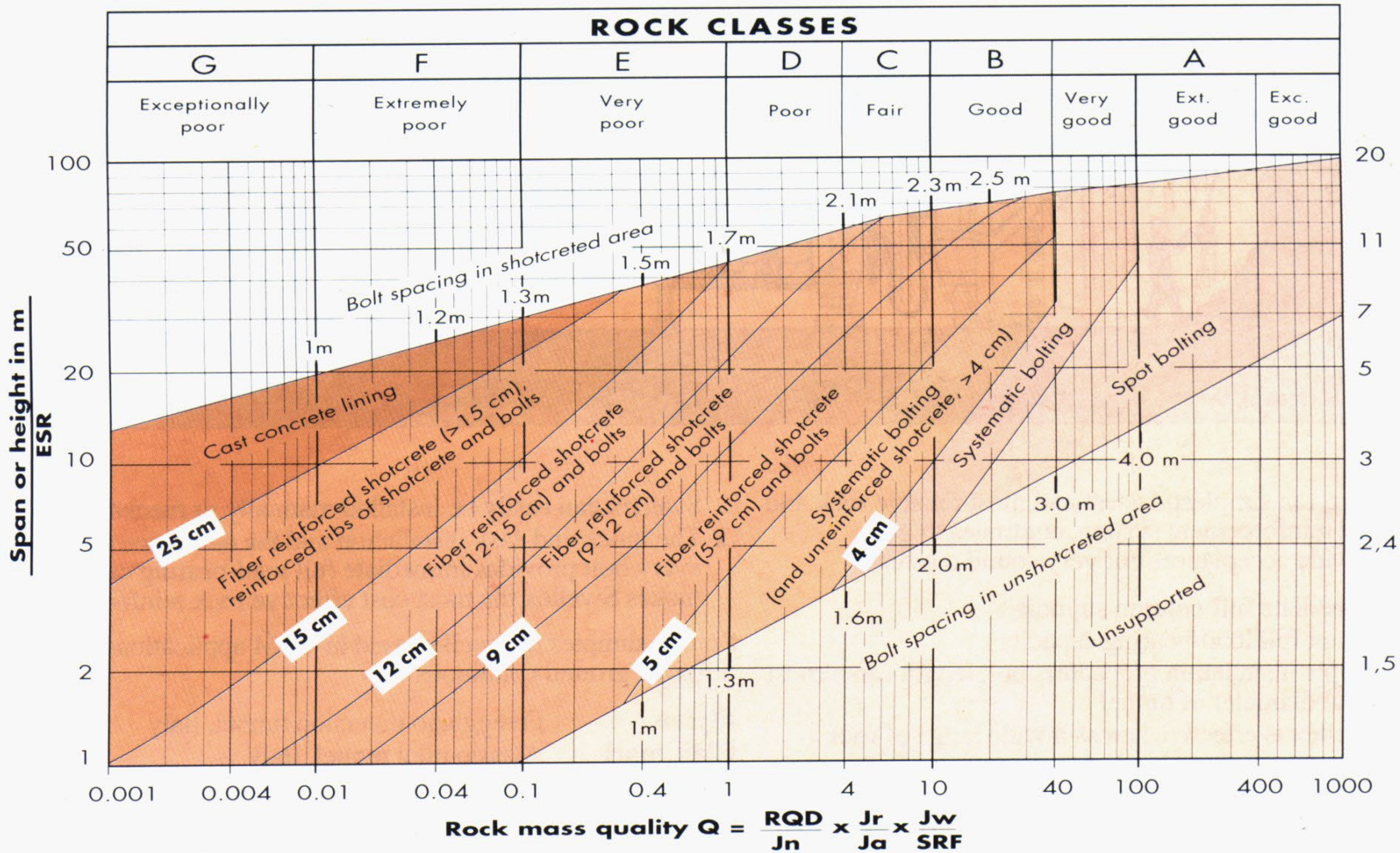
Equivalent dimension is defined as follows:

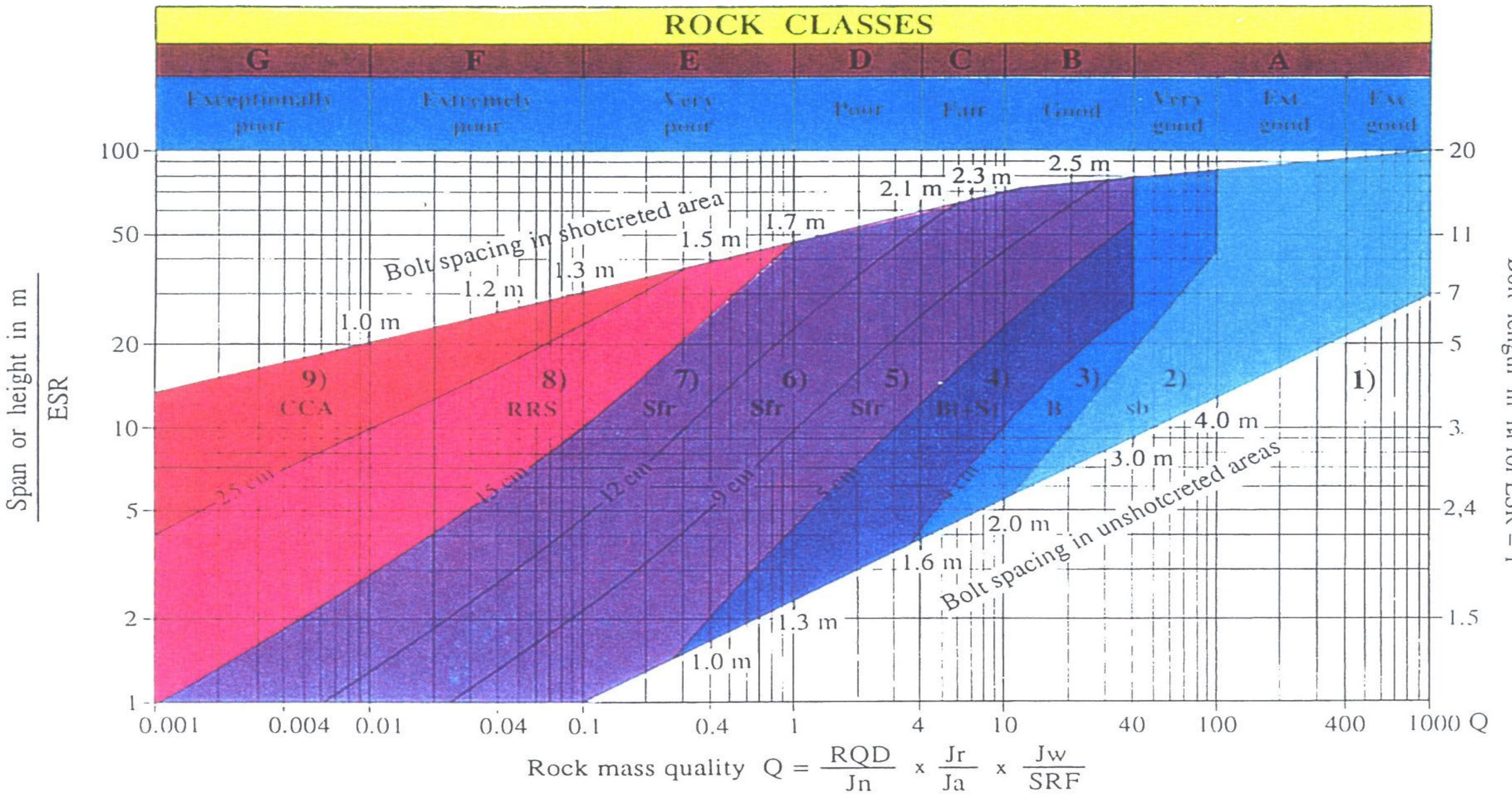
$$D_e = \frac{\text{excavation span, diameter, or height,}}{\text{excavation to support ratio (ESR)}}$$

VALUES OF EXCAVATION SUPPORT RATIO, ESR (BARTON ET AL, 1974)

S. No.	Type of Excavation	ESR
1	Temporary mine openings, etc.	3 – 5 ?
2	Vertical shafts: (i) Circular section (ii) Rectangular / square section	 2.5 ? 2.0 ?
3.	Permanent mine openings, water tunnels for hydro power, etc.	1.6
4.	Storage rooms, water treatment plants, minor road and railway tunnels, etc.	1.3
5.	Oil storage caverns, power stations, major road and railway tunnels, civil defense chambers, etc.	1.0
6.	Underground nuclear power stations, railway stations, sports and public facilities, factories, etc.	0.8 ?

Q-SYSTEM GROUND SUPPORT

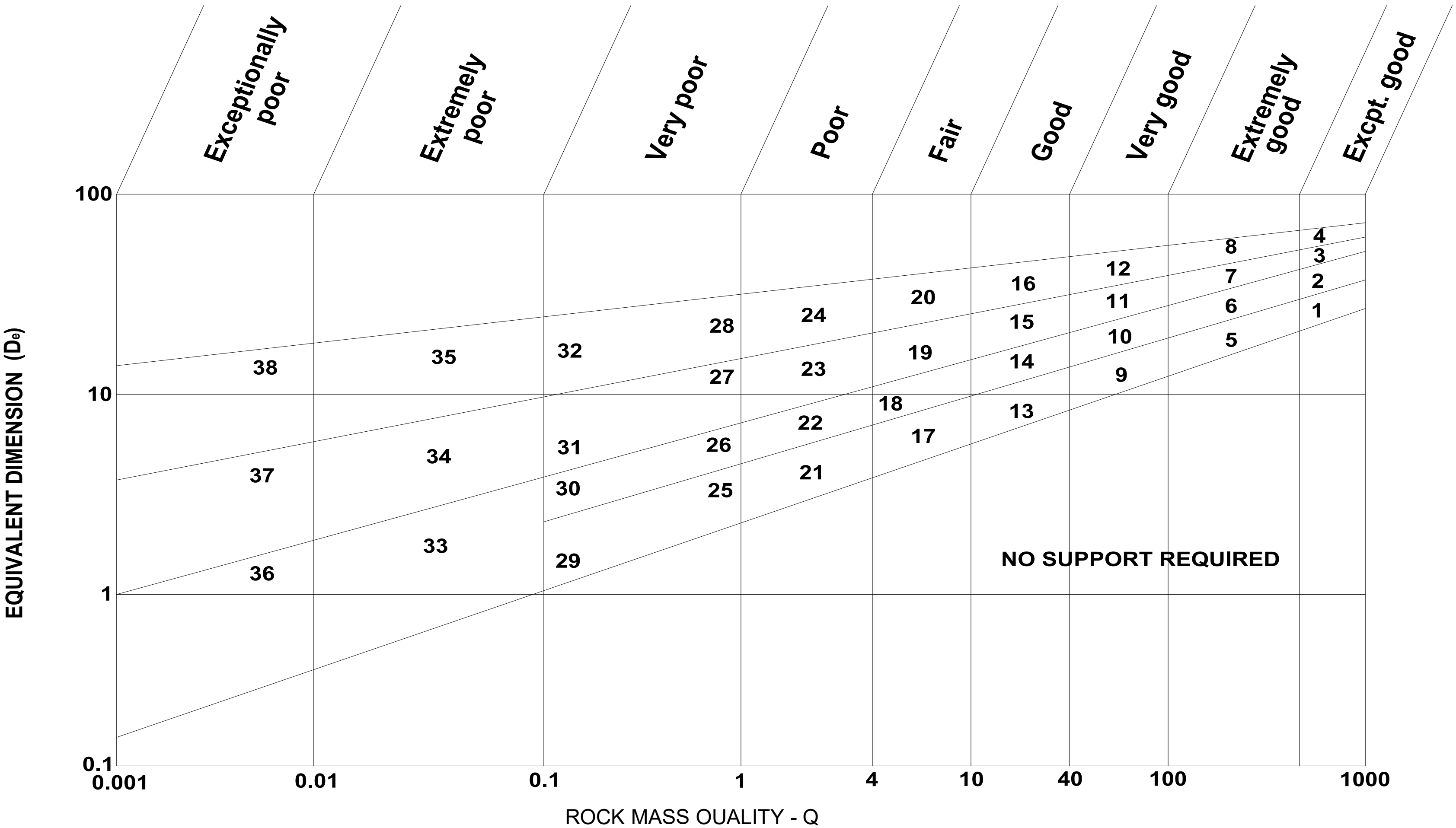




REINFORCEMENT CATEGORIES

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

Q-SYSTEM, EXCAVATION SUPPORT CHART (BARTON ET AL, 1974)

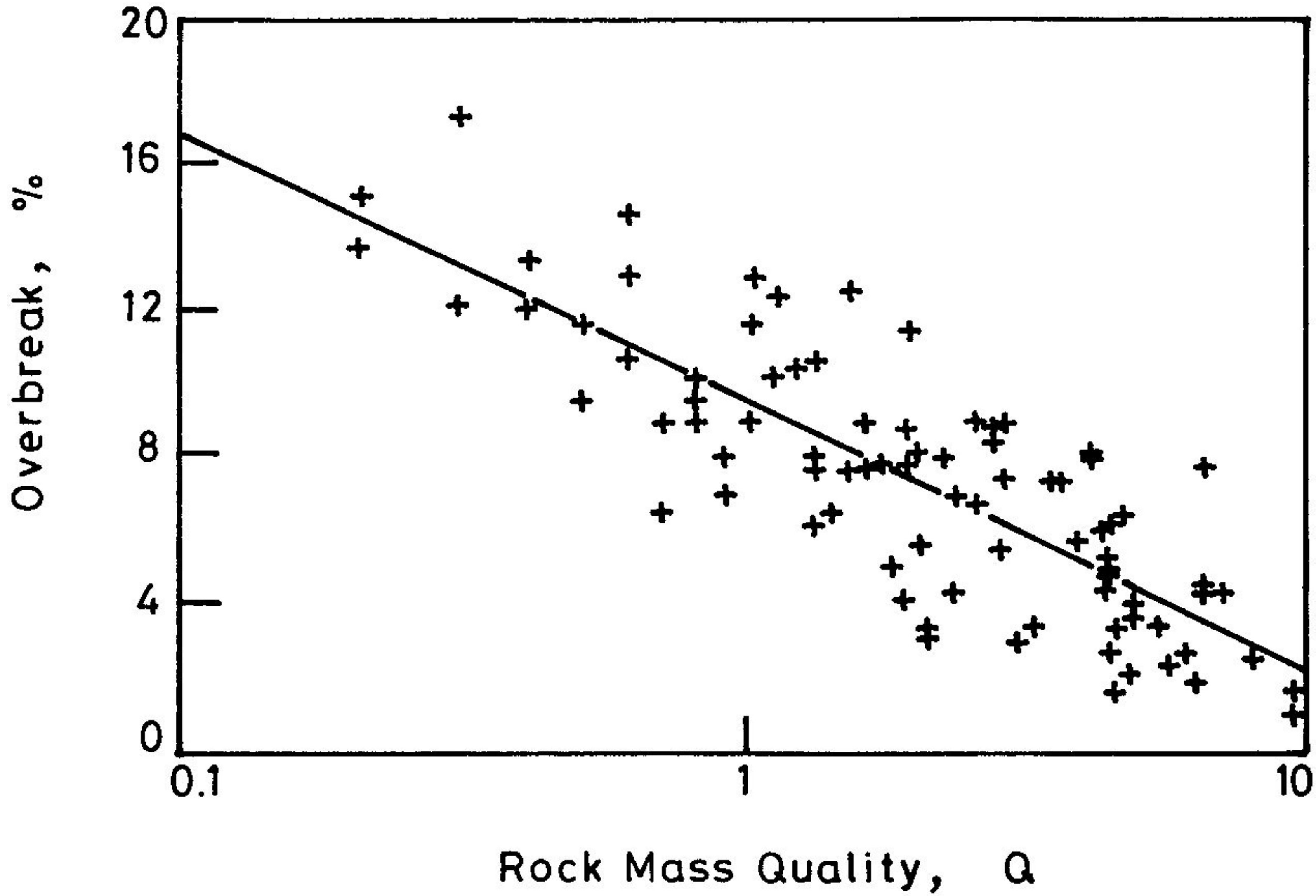


SUMMARY OF COMPARISON BETWEEN RQD AND Q-SYSTEM

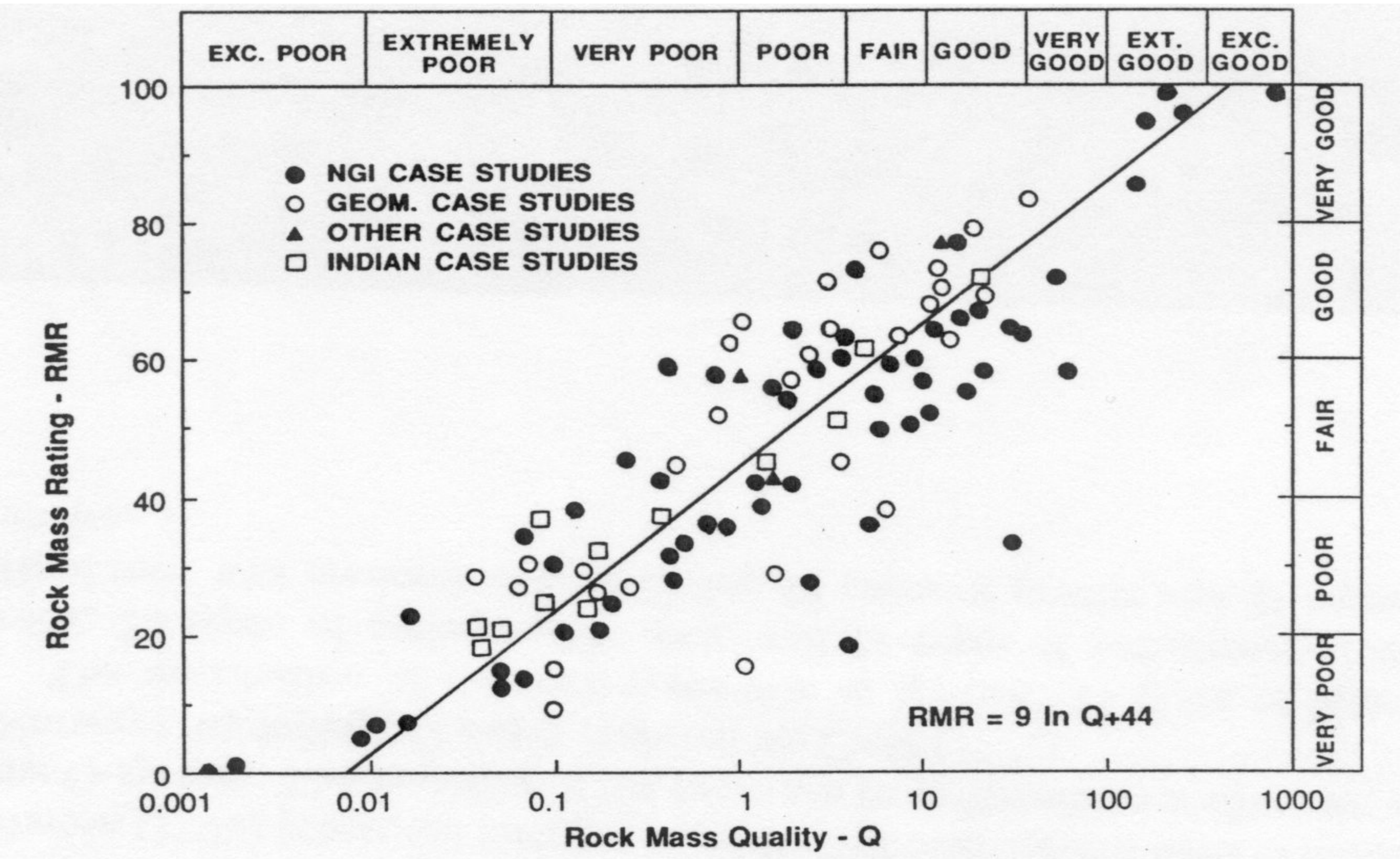
ARMA

Rock quality	Best	Medium	Poor
J_n	3	4	9
J_r	2	2	1
J_a	1	2	4
J_w	1	1	0.66
SRF	1	1	2.5
RQD	100	90	70
Q	67	22	0.5

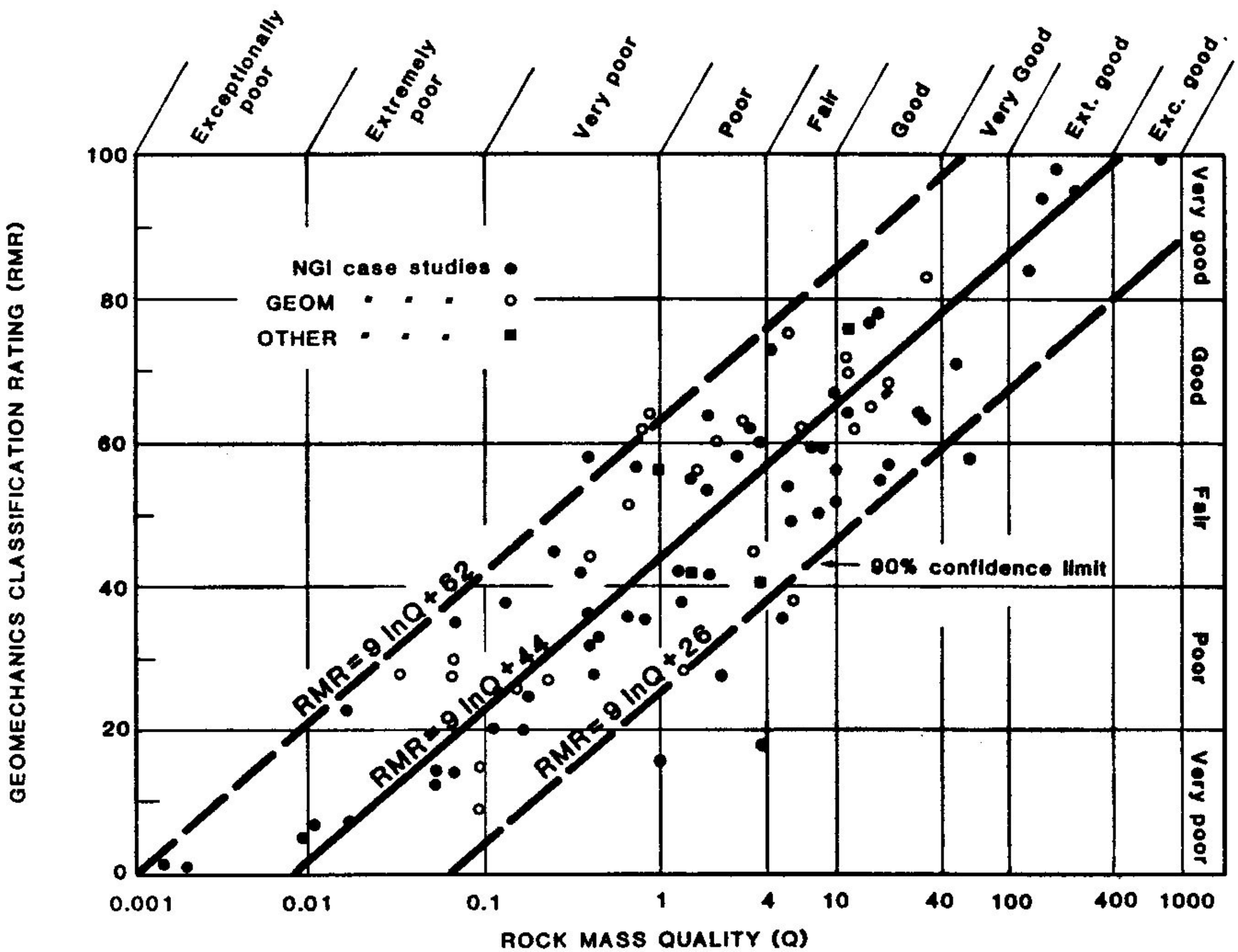
Q-SYSTEM USED TO ESTIMATE TUNNEL OVERBREAK (FRANKLIN, 1993)



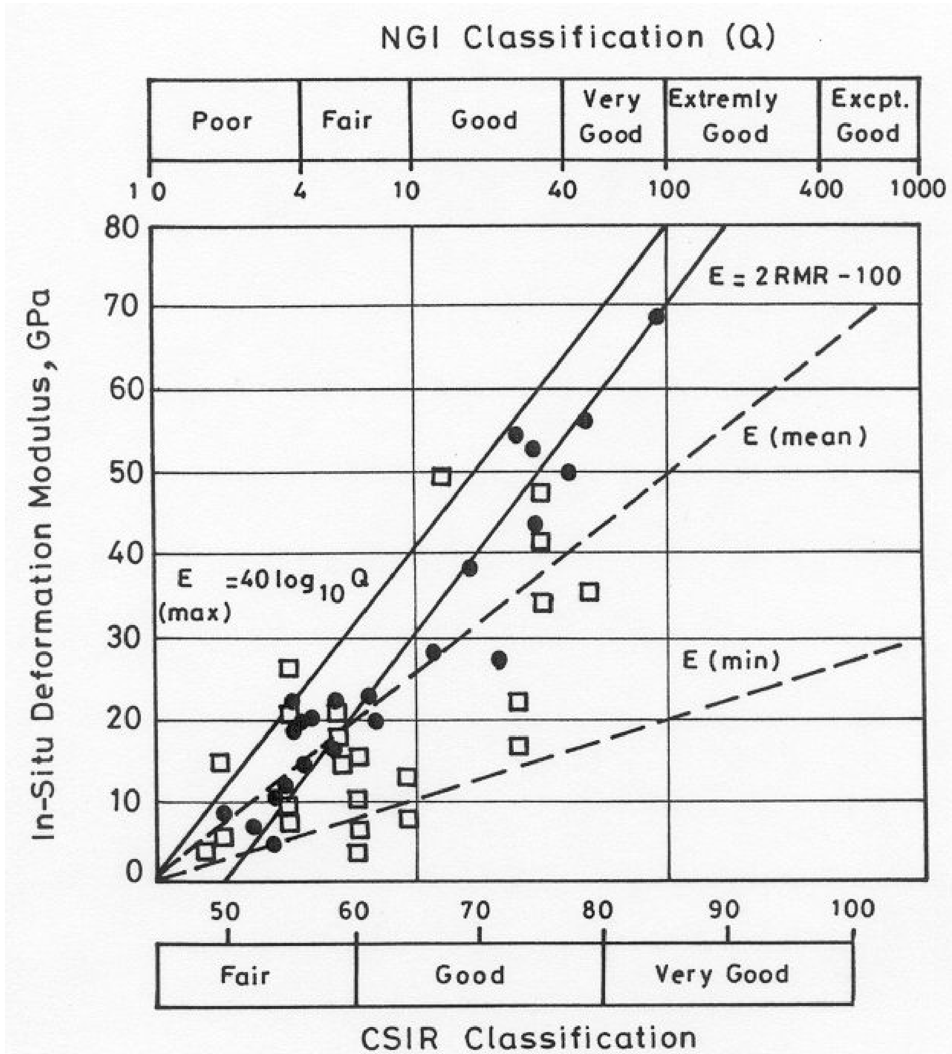
COMPARISON OF RMR TO Q (SINGH AND GOEL, 1999)



RMR AS COMPARED TO Q



Q AND RMR USED TO ESTIMATE MODULUS OF DEFORMATION (BARTON, 1993)



RECOMMENDATIONS ON THE USE OF ROCK MASS CLASSIFICATIONS (BIENIAWSKI, 1988, LACHEL, 2003)

ARMA

- **Do not use the classification schemes as rigid guidelines or a substitute for sound engineering judgment**
- **Consider alternate classifications schemes**
- **Classification schemes are not applicable to all situations**
- **Classification schemes are based on successfully completed projects and as such are typically conservative**
- **Generally, RMR and the Q-system appear to give better, more consistent results**
- **Integrate classification schemes with analytical and observational approaches**

RECOMMENDATIONS ON THE USE OF ROCK MASS CLASSIFICATIONS (BIENIAWSKI, 1988, LACHEL, 2003) cont.

- **There is still a great deal of subjectivity is assigning values to the factors**
- **Anisotropy and inhomogeneity must always be considered**
- **At least two schemes should be applied and it may be possible to develop a site related approach**
- **One classification will normally not be applicable to an entire site**
- **The results of all analysis must be confirmed during construction**
- **A complete record or database of experience with the classification system should be maintained**