OBSERVATIONAL METHOD AND INSIGHT IN THE MOST COMMON DESIGN APPROACHES FROM THAT POINT OF VIEW

by

A. PANCIERA

LOMBARDI ENGINEERING LIMITED, GIUBIASCO (SWITZERLAND)

andrea.panciera@lombardi.group

AGENDA

- Premises and Objective and Intent
- Observational Method and Hazard Scenario Method
- Limits of some design approaches

PREMISE

The concepts and particularities exposed herein relevant to the Observational Method are essentially valid for conventional excavation (drill & blast, road header, jackhammer, ripper).

The approach can be applied without limitations to the excavation with TBM (open, with shield or double shield), with EPB, with slurry shield TBM, or with mix or hybrid technology.

In these cases, the approach has to be calibrated to the relevant particularities of these mechanical excavation technologies and relevant critical situations.

OBJECTIVE

The aim is to try to define and present the most general and all-encompassing approach to tunnel design

The complex nature of Himalayan geology and its way of react to tunnel construction makes the design through known approaches intrinsically insufficient

⚠ **D I S C L A I M E R** ⚠

(…to avoid any technical-diplomatic incident…)

The aim is not to make any judgement of the classification methods and design approaches themselves

(RMR, Q, GSI, NATM, ADECO-RS, etc.)

OBJECTIVE

- Characteristics of the project and its finalization
- Ascertaining the geological features for defining the boundary condition for the project execution under safe conditions
  - Determinant situations has to be identified in detail as per available information
  - Geological survey and investigations
- Differentiating the solution patterns according to the above
  - Geomechanical and coupled hydraulic conditions in the rock mass, structural verifications
- Under considerations of the risk aspects
- Construction and progressive adjustments according to the monitoring and other observed aspects.

OBJECTIVE - Characteristics of the project

Road tunnel

OBJECTIVE - Characteristics of the project

Railway tunnel

OBJECTIVE - Characteristics of the project

Ancillary works
for MEP

OBJECTIVE - Characteristics of the project and of the construction method

Cavern for shaft lift and construction management in hard rock - Bolts and shotcrete

Diagonal link in multifunction station
Tunnel in squeezing rock - Steel ribs and shotcrete

OBJECTIVE - Characteristics of the construction method and equipment

D&B excavation, jumbo perforation and anchor drilling

OBJECTIVE - Characteristics of the construction method and equipment

Excavation and support by means of a hanging installation in squeezing rock

Eurocode 7 (1997) Art. 2.7 Abstract: Observational Method

1. *Because prediction of geotechnical behaviour is often difficult, it is sometimes appropriate to adopt the approach known as ‚the observational method', in which the design is reviewed during construction. When this approach is used the following four requirements shall all be made before construction is started:*
   the limits of behaviour which are acceptable shall be established.
   the range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits.
   a plan of monitoring shall be devised which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage; and with sufficiently short intervals to allow contingency actions to be undertaken successfully. The response time of the instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system.
   a plan of contingency actions shall be devised which may be adopted if the monitoring reveals behaviour outside acceptable limits.

2. *During construction the monitoring shall be carried out as planned and additional or replacement monitoring shall be undertaken if this becomes necessary. The results of the monitoring shall be assessed at appropriate stages and the planned contingency actions shall be put in operation if this becomes necessary."*

INTENT

Observational Method **is not** the NGI handbook, **is not** NATM, **is not** ADECO, **is not** AFTES approach.

NGI handbook **is part of** the Observational Method, NATM **is part of** the Observational Method, ADECO-RS **is part of** the Observational Method, AFTES approach **is part of** the Observational Method.

The **intent** is to focalize the Clients and especially the Designers into avoiding prefabricated receipts, adopting a generalized approach with no labels, names or flags, able to cover in **three moments** the path to an efficient and reliable design.

- Observational Method (defining the whole process),
- Hazard Scenarios (and defining investigations and rock mass classification) and
- Geomechanical Analyses.

OBSERVATIONAL METHOD

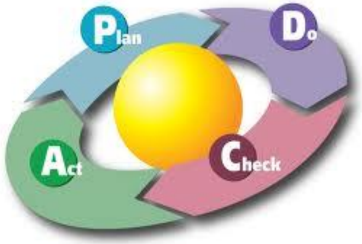
***Identify the hazard scenarios** by a thorough investigation of the surrounding conditions (including the construction methods)*

***Formulate the suitable solutions** and the relevant conditions for their application (and proceed to the required analyses)*

***Procure a feedback** during construction by monitoring and compiling a complete journal*

***and use the data** for actually improving/optimize*

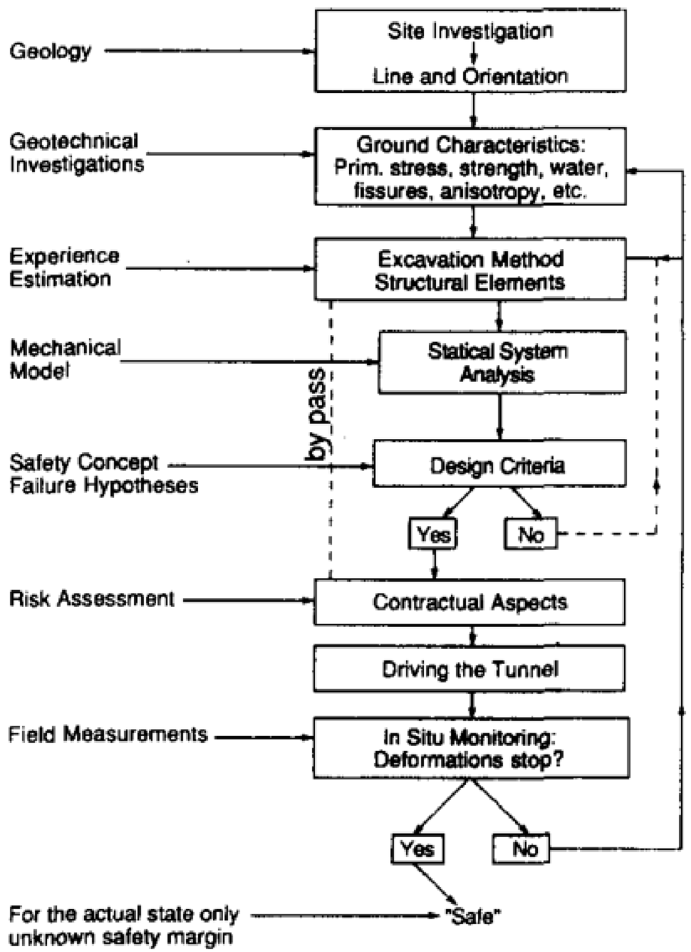
*Studying the results as a renovated base for the **optimization of the circle,***
Planning the adjustments

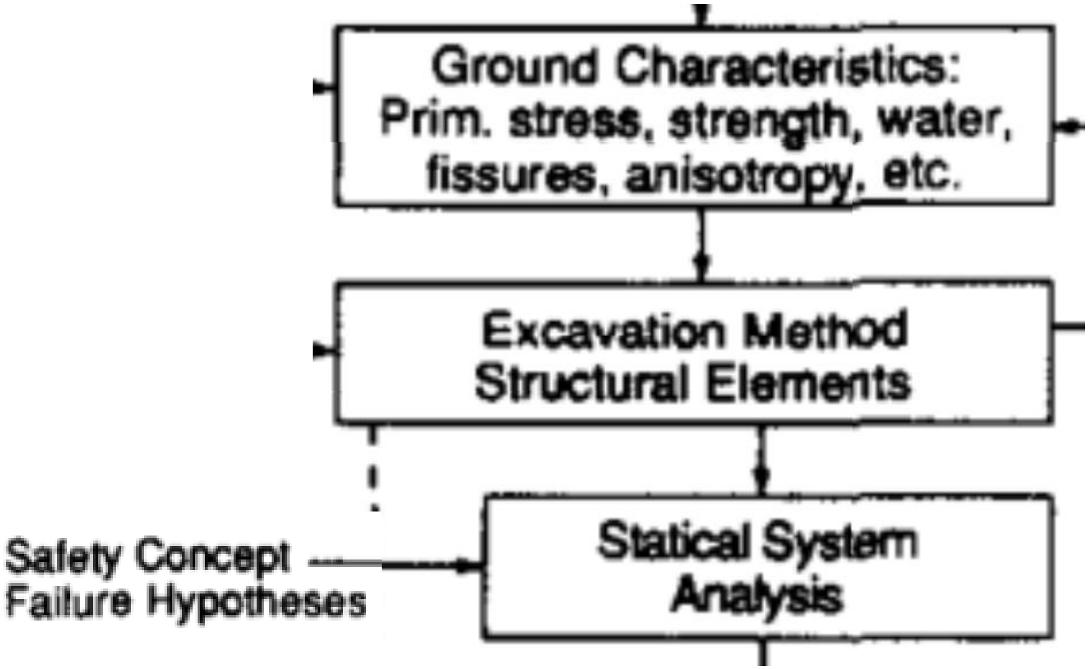


PDCA quality cycle, 1950-52, Deming (development plan for the Japanese industry) then PDSA in 1982

OBSERVATIONAL METHOD

ITA guidelines (1988)





It left missing or implicit a significant point: the situations have to be well framed, significant for the project accomplishment

OBSERVATIONAL METHOD - HAZARD SCENARIOS

Within the cycle typical of the Observational Method, the initial steps of planning and study have to be specifically outlined for tunnelling projects.

The defining element of the design process, is the formal identification of the possible situations that can perturb the construction and the equilibrium of an underground work or, as one can say, the set of possible scenarios leading to damages or to further risks for the underground opening.

A multi-systemic approach has to be implemented for investigating the situations potentially expected and expectable, and for studying solutions that should be considered. This is mentioned, for instance, in the Swiss codes, through the definition of **hazard scenarios** (Gefährdungsbilder in the original German version of the relevant standards and norms).

This approach was sketched in its earliest version of SIA198 since 1984, up to be fully formulated in the last version of SIA197 in 2004, dedicated to the design of underground works.

HAZARD SCENARIOS

An incomplete list to consider for investigation and then study (1):

- Block failure (of various geometry and boundary conditions) …
- Plastic deformations and extension of the plastic zone …
- Soil, soil-like, loose rock conditions
- Strain-softening or strain-hardening strength characteristics
- Effect of the overburden
- Effect of the cavity dimensions …
- Effect of the cavity shape (D shape or circular/sub-circular)
- Effect of the constructions sequence
- Effect of nearby cavities or crossing/bifurcations

HAZARD SCENARIOS

An incomplete list to consider for investigation and then study (2):

- Time dependent rock mass characteristics
- Excavation face instability ... (because of overlying loose volumes, of excessive extrusion, of plastic behaviour)
- Swelling …
- Karst …
- Aggressive water and/or thermal water
- Rock burst and spalling by extremely strong rock mass and high overburden
- Fault crossing of various extent and fault gauge nature (clayey or cataclastic)
- Raveling material in highly fractured/disintegrated/disaggregated rock mass structure …

Tunnelling Asia' 2022

Workshop on

Observational Approach in Tunnelling: Evolvement, Issues and Challenge

HAZARD SCENARIOS

An incomplete list to consider for investigation and then study (3):

- Groutability and effect of grouting over the stability of the cavity (different porosity)
- Particular pore pressure conditions in infrastructure tunnels
- Effect of water (on the rock mass characteristics or as acting pressure beyond an aquiclude)
- Leaching/slaking …
- Particular pore pressure conditions in water transportation tunnels (under pressure) and relevant hydrojacking/hydrofracturing …
- Effect of the internal water pressure (during operation) on the surrounding rock, on the tunnel, on nearby cavities
- Effect of the transients

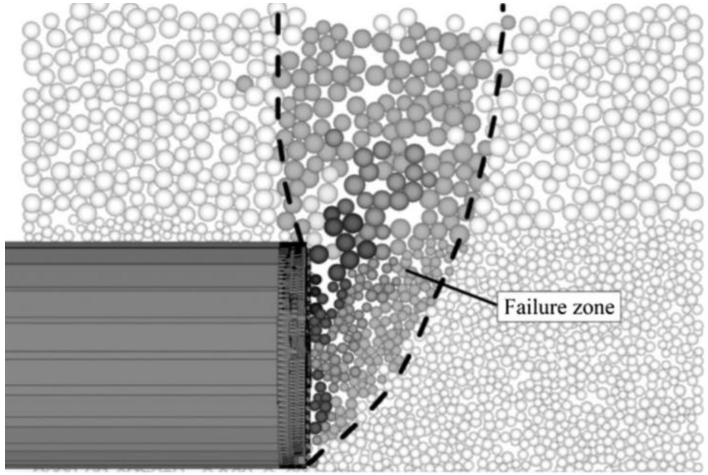
And the possible combination of several amongst these ones into specific situations.

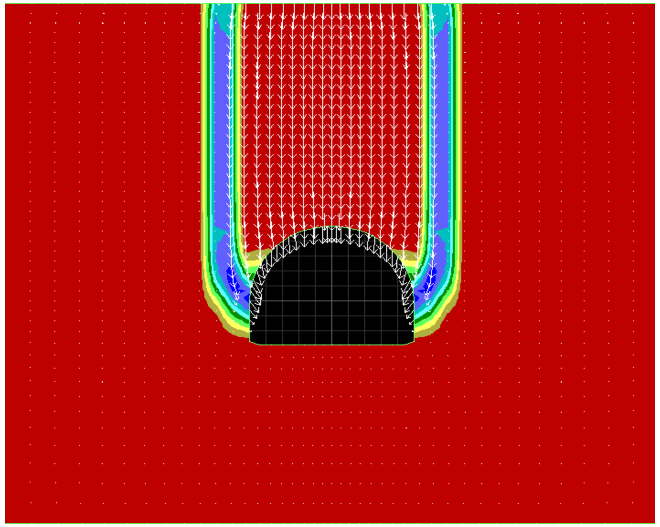
Kargi, 2015 (Turkey)

HAZARD SCENARIOS

As well as all conditions typical for shallow tunnels:

- Chimney rupture at the tunnel face
- Terzaghi rupture at the tunnel section
- Solid transportation and retrograde erosion in sand lenses
- etc.





OBSERVATIONAL METHOD - HAZARD SCENARIOS

Implicit base
(but not so trivial, especially in the Indian context because of accessibility and budget):

General investigations and targeted investigations, mappings and other surveys are paramount
(e.g. bibliographical, topographical, geostructural, geological, hydrogeological, geophysical)

OBSERVATIONAL METHOD - HAZARD SCENARIOS

The approach by the **Observational Method with definition of Hazard Scenarios** is valid, leading to a successful definition of the excavation method, the sequences and the support measures being applicable for all situations and type of tunnel (deep, shallow, hydraulic, railway, highway) independently from its dimensions and cover and from the rock mass nature. All these aspects will have to concur into the engineering studies and relevant an analyses for the project. The presented cases refer to tunnels executed by conventional excavation. It is however conceptually applicable also in case of mechanized excavation.

OBSERVATIONAL METHOD - HAZARD SCENARIOS

It is a generalized approach without labels, names or flags, making able to provide an efficient and reliable design through **three steps**:

- Application of the **Observational Method** defining the whole cyclic process
- Definition of the **Hazard Scenarios** (and implicit investigations and rock mass classification)
- **Geomechanical Analyses** (not subject of this presentation) leading to the design and construction solutions

During the work execution, thy cyclic process of the **Observational Method** shall be supported by the monitoring, the data interpretation and the consequent calibration/adjustment of the design solutions

OBSERVATIONAL METHOD - HAZARD SCENARIOS

…

Actually, no one of the known approaches considers the typical step of the **hazard scenarios**

Not as far as these methods are known, and not explicitly.

Fw remarks to the Austrian approach are exposed later in the presentation.

(implicit hints are there, especially in the most modern revisiting of these design approaches)

Some few examples follow, about the limits of the known and quite successful approaches

… until some of the limits appear.

LIMITS OF ROCK MASS CLASSIFICATION TO DEFINE DESIGN SOLUTION

Prof. Bieniawski: Engineering Rock Mass Classification (1989), Introduction (§ 1.1 and § 1.2):

Modern rock mass classifications have never been intended as the ultimate solution to design problems, but only a means toward this end.

When used correctly and for the purpose for which they were intended, rock mass classifications can be powerful aids in design.

They were not intended to replace analytical studies, field observations and measurements, nor engineering judgment.

This short passage of the introduction should lead so many ISO and standard-fond engineers to think to the far wider reality of a tunnel design, which cannot be systematically squeezed into any kind of standardized and ruled methodology or philosophy.

Standards are helpful, but engineering is it more.

LIMITS OF OTHER METHODS & APPROACHES - NGI, Barton - Q-system

Q = (RQD/Jn) • (Jr/Ja) • (Jw/SRF) Barton, 1974

Q is logarithmic, theoretically scoring between 0.001 and 1000
It considers as parameters : RQD, the Joint set number Jn, the Joint roughness number Jr (most unfavourable discontinuities), the Joint alteration number Ja (most weathered conditions of discontinuities and infill material), the Joint water reduction factor (considering and the Stress reduction factor SRF

The three factors can be interpreted as:

- The potential size of blocks
- The component of the inter-block shear strength
- The active initial state of the rock mass as regards water and stresses.

Table 6 SRF-values.

Barton, 1974

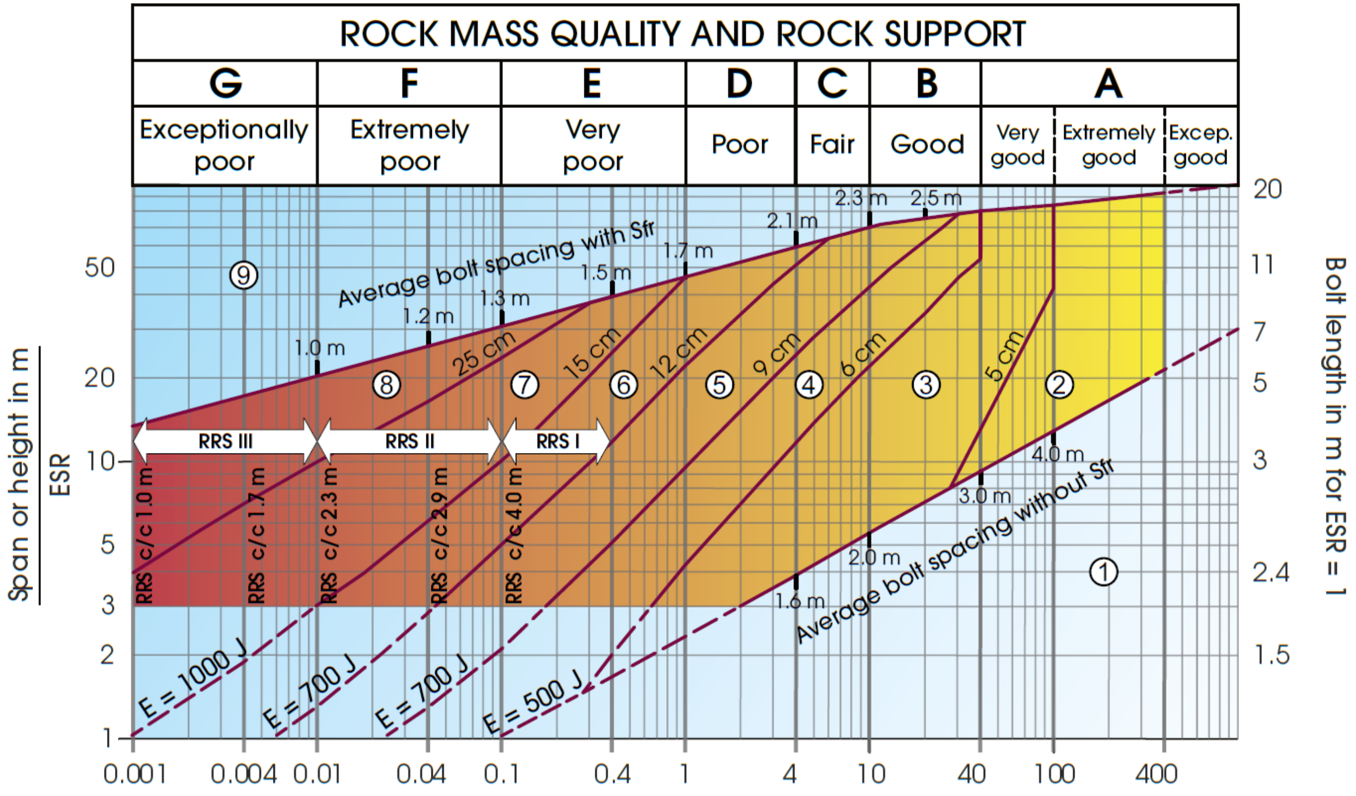
6	Stress Reduction Factor			SRF
	a) Weak zones intersecting the underground opening, which may cause loosening of rock mass			
A	Multiple occurrences of weak zones within a short section containing clay or chemically disintegrated, very loose surrounding rock (any depth), or long sections with incompetent (weak) rock (any depth). For squeezing, see 6L and 6M			10
B	Multiple shear zones within a short section in competent clay-free rock with loose surrounding rock (any depth)			7.5
C	Single weak zones with or without clay or chemical disintegrated rock (depth ≤ 50m)			5
D	Loose, open joints, heavily jointed or "sugar cube", etc. (any depth)			5
E	Single weak zones with or without clay or chemical disintegrated rock (depth > 50m)			2.5
	Note: i) Reduce these values of SRF by 25-50% if the weak zones only influence but do not intersect the underground opening			
	b) Competent, mainly massive rock, stress problems	σ_c / σ_1	σ_θ / σ_c	SRF
F	Low stress, near surface, open joints	>200	<0.01	2.5
G	Medium stress, favourable stress condition	200-10	0.01-0.3	1
H	High stress, very tight structure. Usually favourable to stability. May also be unfavourable to stability dependent on the orientation of stresses compared to jointing/weakness planes*	10-5	0.3-0.4	0.5-2 2-5*
J	Moderate spalling and/or slabbing after > 1 hour in massive rock	5-3	0.5-0.65	5-50
K	Spalling or rock burst after a few minutes in massive rock	3-2	0.65-1	50-200
L	Heavy rock burst and immediate dynamic deformation in massive rock	<2	>1	200-400

Note: ii) For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c to $0.75\,\sigma_c$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c to $0.5\,\sigma_c$, where σ_c = unconfined compression strength, σ_1 and σ_3 are the major and minor principal stresses, and σ_θ = maximum tangential stress (estimated from elastic theory)

iii) When the depth of the crown below the surface is less than the span; suggest SRF increase from 2.5 to 5 for such cases (see F)

	c) Squeezing rock: plastic deformation in incompetent rock under the influence of high pressure	σ_θ / σ_c	SRF
M	Mild squeezing rock pressure	1-5	5-10
N	Heavy squeezing rock pressure	>5	10-20
	Note: iv) Determination of squeezing rock conditions must be made according to relevant literature (i.e. Singh et al., 1992 and Bhasin and Grimstad, 1996)		

	d) Swelling rock: chemical swelling activity depending on the presence of water	SRF
O	Mild swelling rock pressure	5-10
P	Heavy swelling rock pressure	10-15



Rock mass quality $Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$

Barton, 2008
The definition of Q remains unchanged as per Barton, 1974

LIMITS OF OTHER METHODS & APPROACHES - NGI, Barton - Q-system

NGI, in their handbook, 2015, mentions some limitations to the Q-system (par. 1.3):

The majority of the case histories are derived from mainly hard, jointed rocks including weakness zones. From soft rocks with few or no joints there are only few examples, and by evaluation of support in such types of rocks, other methods should be considered to be used in addition to the Q-system for support design.

The Q-system may not give any satisfactory description of the stability situation, and other methods such as deformation measurements and/or numerical modelling for support design may be used additionally.

I would rather say "instead".

LIMITS OF OTHER METHODS & APPROACHES - Bieniawski - RMR

RMR89 = A1 + A2 + A3 + A4 + A5 + B Bieniawski, 1989

Developed initially in 1973, updated in the presently applied version 1989.

It characterizes and classifies the rock mass through 5 parameters (UCS, RQD, joint spacing, joint conditions, groundwater conditions) and one adjustment factor (the joint orientation with respect to the excavation face).

The result is the linear parameter RMR (89), with values between 0 and 100, dividing the rock mass in the 5 classes I to V.

TABLE 4.1 The Rock Mass Rating System (Geomechanics Classification of Rock Masses)*

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Ranges of Values						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4–10	2–4	1–2	For this low range, uniaxial compressive test is preferred		
		Uniaxial compressive strength (MPa)	>250	100–250	50–100	25–50	5–25	1–5	<1
	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 discontinuities		>2 m	0.6–2 m	200–600 mm	60–200 mm	<60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered wall	Slickensided surfaces or Gouge < 5 mm thick or Separation 1–5 mm Continuous	Soft gouge > 5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (L/min)	None	<10	10–25	25–125	>125		
		or Ratio Joint water pressure / Major principal stress	or 0	or <0.1	or 0.1–0.2	or 0.2–0.5	or >0.5		
		or General conditions	or Completely dry	or Damp	or Wet	or Dripping	or Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS

Strike and Dip Orientations of Discontinuities		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
Ratings	Tunnels and mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

C. 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

D. MEANING OF ROCK MASS CLASSES

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

*After Bieniawski (1979).

By the straight application of this method, difficulties rise to the designer every time that the rock mass tends to be weak, deformable and presents phenomena like squeezing or swelling. In these cases, the author often defines the conditions as "over-V (fifth)", letting intrinsically understand that the system is not able to cover these conditions.

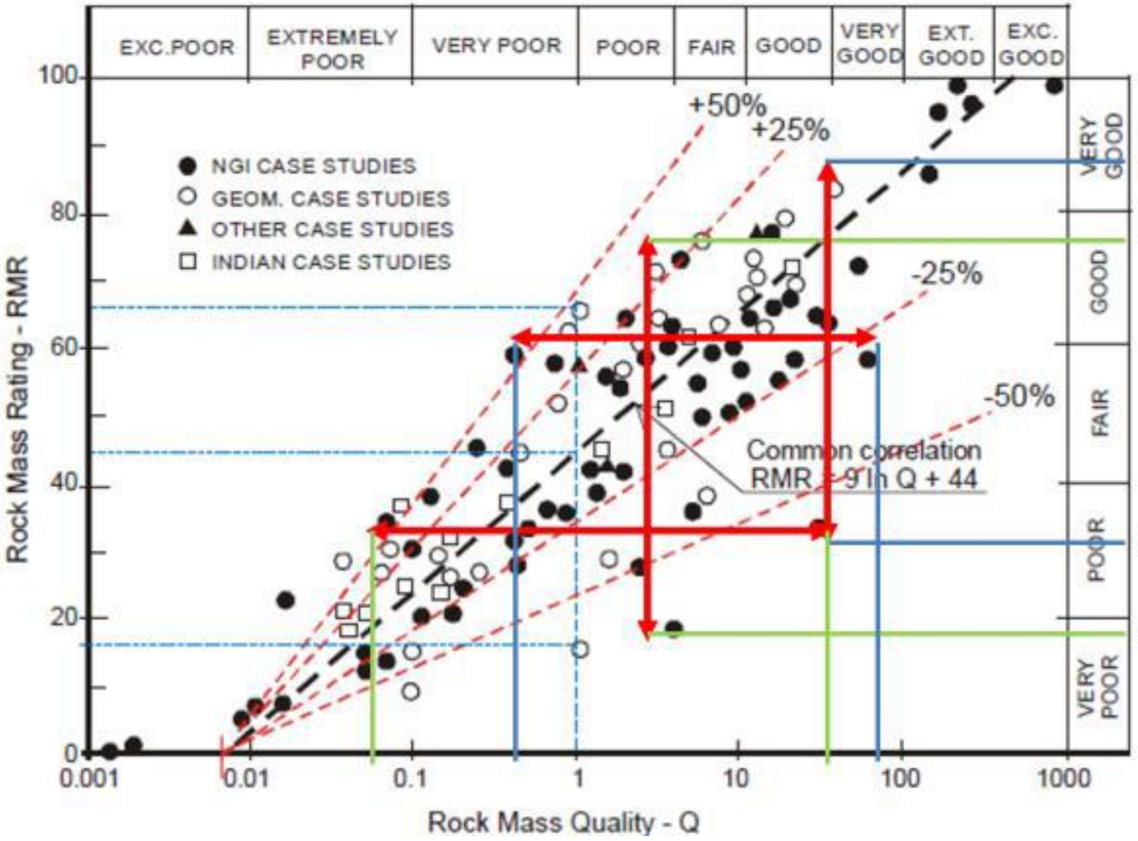
TABLE 4.4 Guidelines for Excavation and Support of Rock Tunnels in Accordance with the Rock Mass Rating System[a]

		Support		
Rock Mass Class	Excavation	Rock Bolts (20-mm Dia, Fully Grouted)	Shotcrete	Steel Sets
Very good rock I RMR:81–100	Full face 3-m advance	Generally, no support required except for occasional spot bolting		
Good rock II RMR:61–80	Full face 1.0–1.5-m advance Complete support 20 m from face	Locally, bolts in crown 3 m long, spaced 2.5 m, with occasional wire mesh	50 mm in crown where required	None
Fair rock III RMR: 41–60	Top heading and bench 1.5–3-m advance in top heading Commence support after each blast Complete support 10 m from face	Systematic bolts 4 m long, spaced 1.5–2 m in crown and walls with wire mesh in crown	50–100 mm in crown and 30 mm in sides	None
Poor rock IV RMR: 21–40	Top heading and bench 1.0–1.5-m advance in top heading. Install support concurrently with excavation 10 m from face	Systematic bolts 4–5 m long, spaced 1–1.5 m in crown and wall with wire mesh	100–150 mm in crown and 100 mm in sides	Light to medium ribs spaced 1.5 m where required
Very poor rock V RMR: <20	Multiple drifts 0.5–1.5-m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting	Systematic bolts 5–6 m long, spaced 1–1.5 m in crown and walls with wire mesh. Bolt invert	150–200 mm in crown, 150 mm in sides, and 50 mm on face	Medium to heavy ribs spaced 0.75 m with steel lagging and fore-poling if required. Close invert

[a] Shape: horseshoe; width: 10 m; vertical stress: <25 MPa; construction: drilling and blasting.

Support proposals according to Bieniawski, 1989

NGI, Barton - Q vs. Bieniawski - RMR (Palmstrom, 2009)



⚠ **to the proposed linearizations !!!**

By the same evaluated conditions:

Looking to same RMR (horizontal arrows, e.g. 30 or 60) ranges in Q result of a factor 100 to nearly 1000.

Looking to same Q value (vertical arrows, e.g. 4 or 50) ranges in RMR result with a class variation from "poor" to "very good" (RMR 30 to 90, classes IV to I) or even from "very poor" to "good" (RMR 20 to 80, classes V to II).

NGI, Barton - Q vs. Bieniawski - RMR (Palmstrom, 2009)

Q and RMR represent a subjective approach

They induce the feeling of a reassuring precision.

This apparent precision of Q and RMR is based on a series of assumptions that require a profound knowledge of the rock mass for fixing numerical partial marks and rates, which are hardly measurable. In deep tunnels this level of knowledge is usually missing.

Already by RQD : by 9 fissures every 11 cm RQD = 100 **but** by 11 fissures every 9 cm RQD = 0

A strict and well postulated consensus about their use has to be finalised already within the design phase (before tendering) but surely before excavation, in order to keep the approach at least homogeneous.

… rock mass classifications have never been intended as the ultimate solution to design problems
… they were not intended to replace analytical studies, field observations and measurements, not engineering judgment (Bieniawski, 1989)

LIMITS OF OTHER METHODS & APPROACHES - NATM (Rabcevicz, Müller, Pacher)

1. The inherent strength of the soil or rock around the tunnel domain should be preserved and deliberately mobilized to the maximum extent possible (rock arch activation).
2. The mobilization can be achieved by controlled deformation of the ground. Excessive deformation that will result in loss of strength or high surface settlement must be avoided.
3. Initial and primary support systems consisting of systematic rock bolting or anchoring and thin, semi-flexible sprayed concrete lining are used to achieve the particular purposes given in.
4. The length of the unsupported span should be left as short as possible.
5. Permanent support works are usually carried out at a later stage, when the still stand of the deformation of the primary support is achieved.
6. The closure of the ring should be adjusted with an appropriate timing that can vary, depending on the soil or rock conditions.
7. Laboratory tests and monitoring of the deformation of supports and ground should be carried out.
8. Those involved in the execution, design, and supervision of NATM construction must understand and accept the NATM approach and react co-operatively on resolving any problems. The contractual bases have to include this.

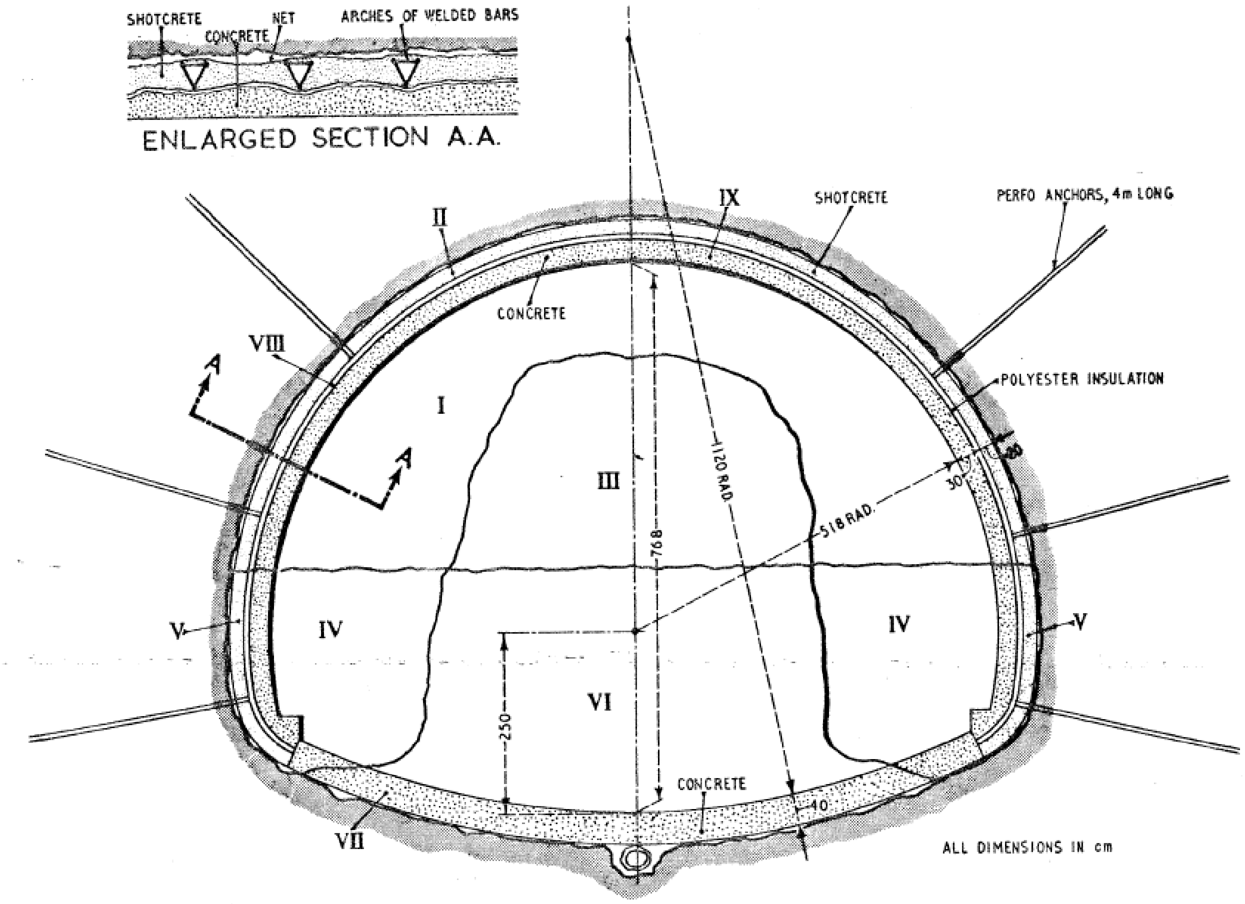


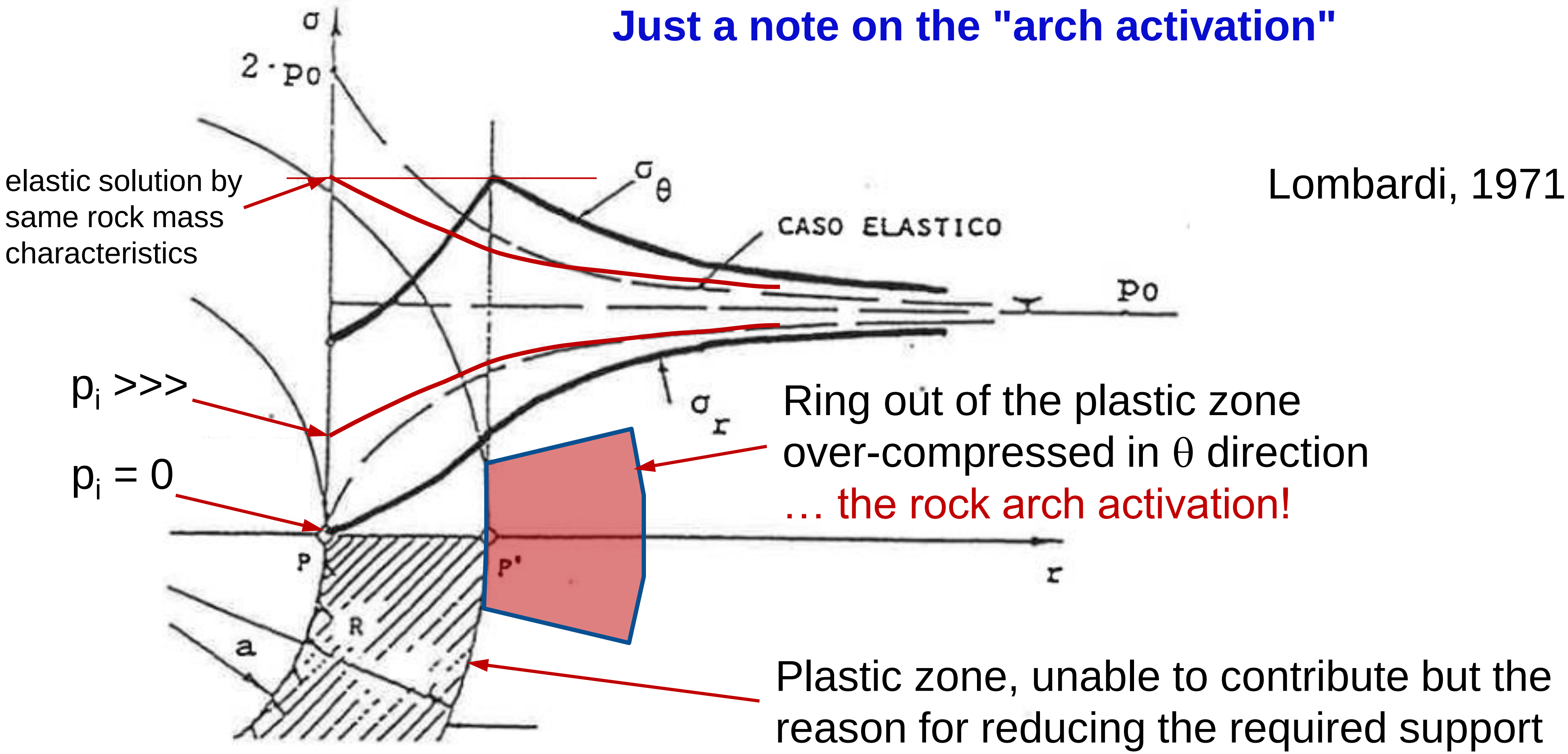
Fig. 21. Construction sequence for road tunnel in southern Austria

Rabcevicz, 1965

NATM basic concept, as it was born and applied for decades: progressive arch activation around the cavity and typical X-section
> Dealing with the rock mass stress state

Obviously, recent applications and experiences brought a far wider pattern of solutions and of cases, studied in much differentiated geological environments than the Alpine one

Just a note on the "arch activation"



Lombardi, 1971

WHAT ABOUT OTHER HAZARD SCENARIOS ??

- Block failure (of various geometry and boundary conditions)
- Soil, soil-like, loose rock conditions
- Aggressive water and/or thermal water
- Rock burst and spalling
- Fault crossing and fault gauge nature
- Groutability and effect of grouting over the stability of the cavity
- Particular pore pressure conditions in infrastructure tunnels
- Effect of water on the rock mass or as acting pressure
- Particular pore pressure conditions in water transportation tunnels
- Effect of the internal water pressure (during operation) on the surrounding rock, on the tunnel, on nearby cavities

- Excavation face instability
- Swelling
- Karst
- Raveling material
- Hydrojacking/hydrofracturing
- Effect of the transients
- Leaching/slaking

NATM reinterpreted in the USA, 2009

Apparently the American engineers , as ones of many in the World in the course of the years, developed the lack in the approach by introducing various other scenarios (here called "Behaviors").
This reinterpretation might be understood as "Evolved NATM"
This is going in the right direction, out of a lacking approach

NATM strategies, so as presented in the US, 2009, Colorado USA

Table 1. Ground behaviors*

Behavior	Description of Failure Modes and Manifestations in an Unsupported Tunnel
Block failures	Discontinuity-controlled, gravity-induced failure of rock blocks that manifests as falling and sliding of blocks.
Raveling	Progressive, discontinuity-controlled failure of small rock blocks within the general rock mass at or near the excavation surface. Raveling is manifested as successive fallout of small rock blocks and can ultimately result in a significant overbreak.
Shallow shear failure	Shallow shear failures result from overstressing of the ground within 0.25D to 0.5D of the tunnel perimeter (D=tunnel diameter) and may be enhanced by the potential for discontinuity and gravity-controlled failure modes. Shallow shear failure is manifested by moderate inward movement of the tunnel perimeter, including invert heave, and possibly by movement of rock into the tunnel opening along discontinuities.
Deep shear failures	Deep-seated shear failures result from overstressing of the ground beyond 0.25D to 0.5D from the tunnel perimeter. Deep-seated shear failure manifests as large radial convergence of the tunnel perimeter, including invert heave.
Slaking/softening	Slaking is the deterioration and breakdown of intact rock upon exposure by excavation and manifests as slabbing of material from the crown and sidewalls. The severity of this behavior is assessed on the basis of slake durability tests performed according to ASTM Test Method 4644. Softening, which is dependent on wetting and exposure by excavation, is the reduction of intact rock strength at the invert or elsewhere and manifests as the development of a muddy or unstable invert or sloughing along segments of the tunnel perimeter elsewhere.
Swelling	Swelling occurs due to absorption of water by clay minerals in rock upon excavation-induced unloading. Swelling manifests as movement of the ground into the tunnel opening or additional tunnel support loading.
Crown instability due to low cover	Excessive crown geological overbreak and chimney-type failure will occur due to lack of confinement under low-cover reaches at portals. It manifests as block fallout and raveling above the crown.

*Modified from Austrian Society for Geomechanics, 2004.

LIMITS OF OTHER METHODS & APPROACHES
ADECO-RS (Lunardi)

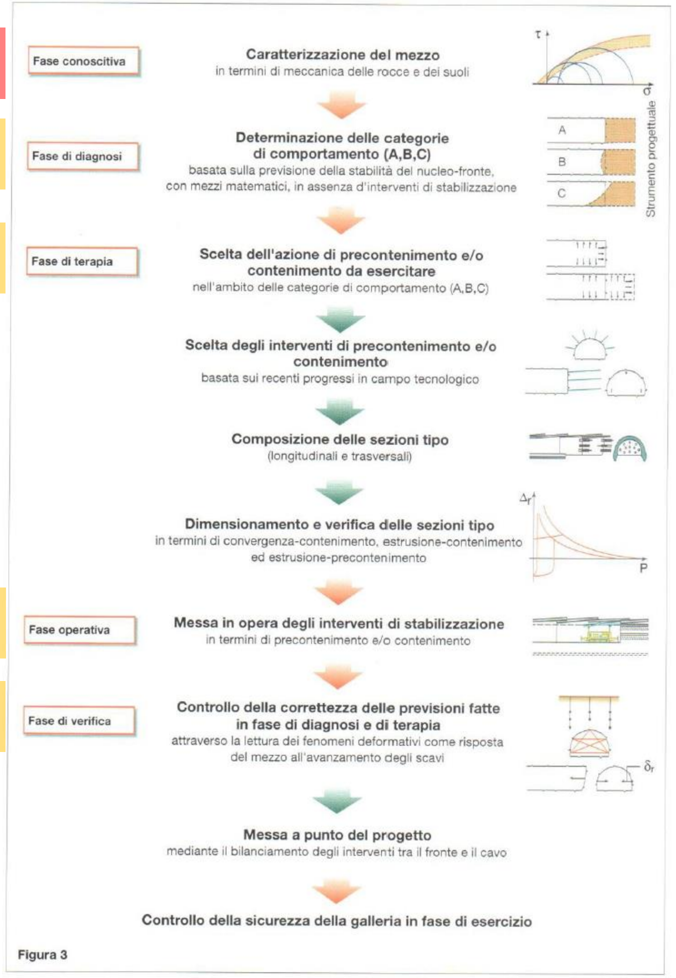
Characterisation (Investigation)

Diagnosis (analysis)

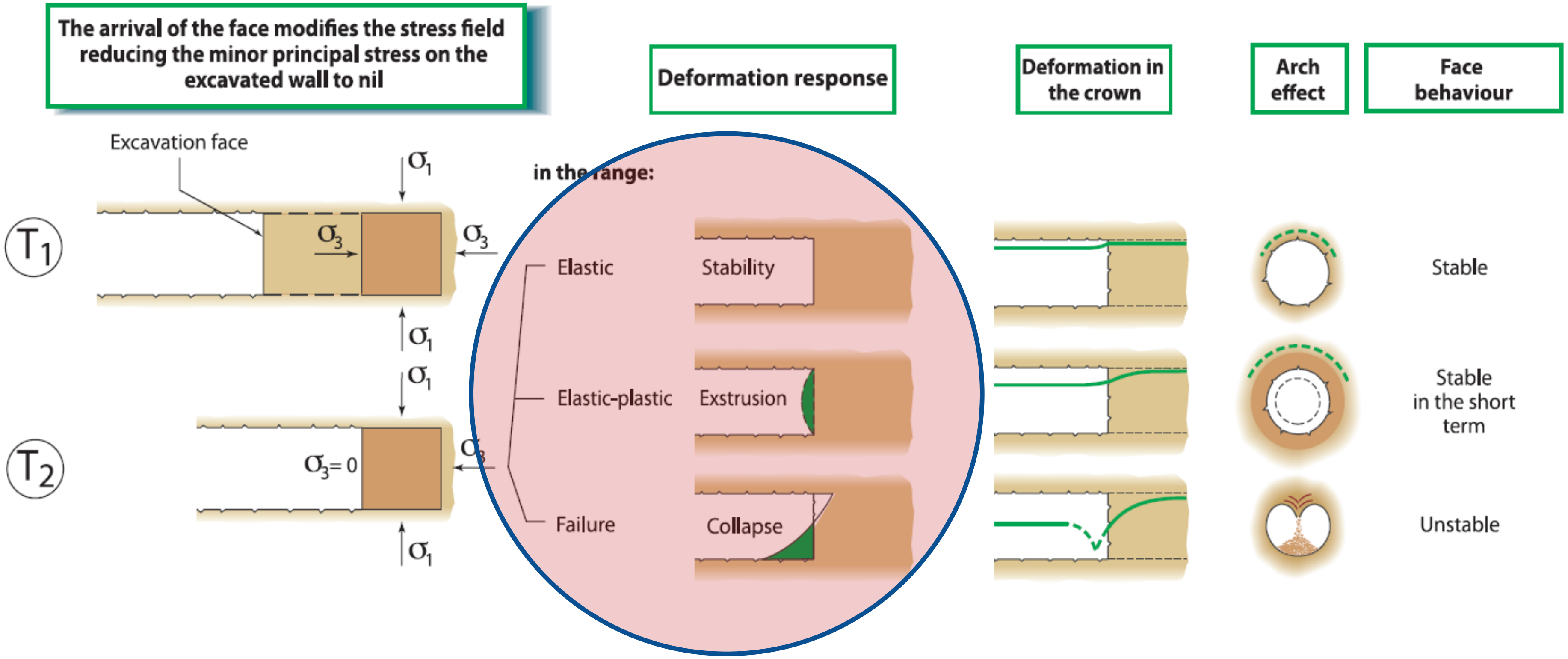
Therapy (solution for controlling the conditions)

Operation (implementation/construction)

Monitoring



Design and activity phases (Lunardi, 2006)



ADECO-RS concept, based on the sole face stability conditions - Diagnosis

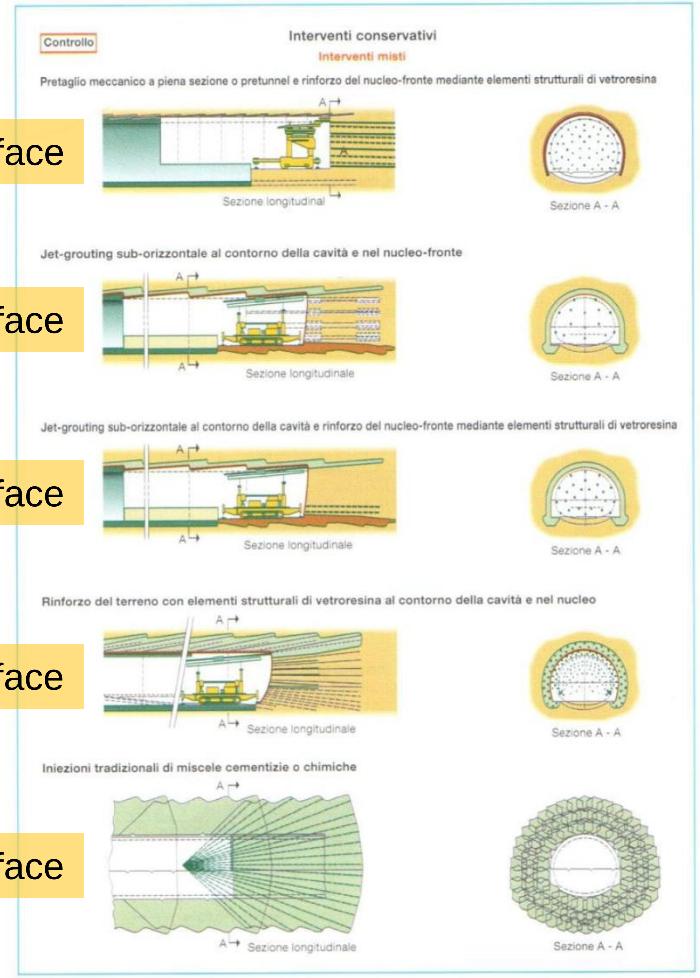
Forepoling at the profile and fibreglass at the face

Jet grouting at the profile and at the face

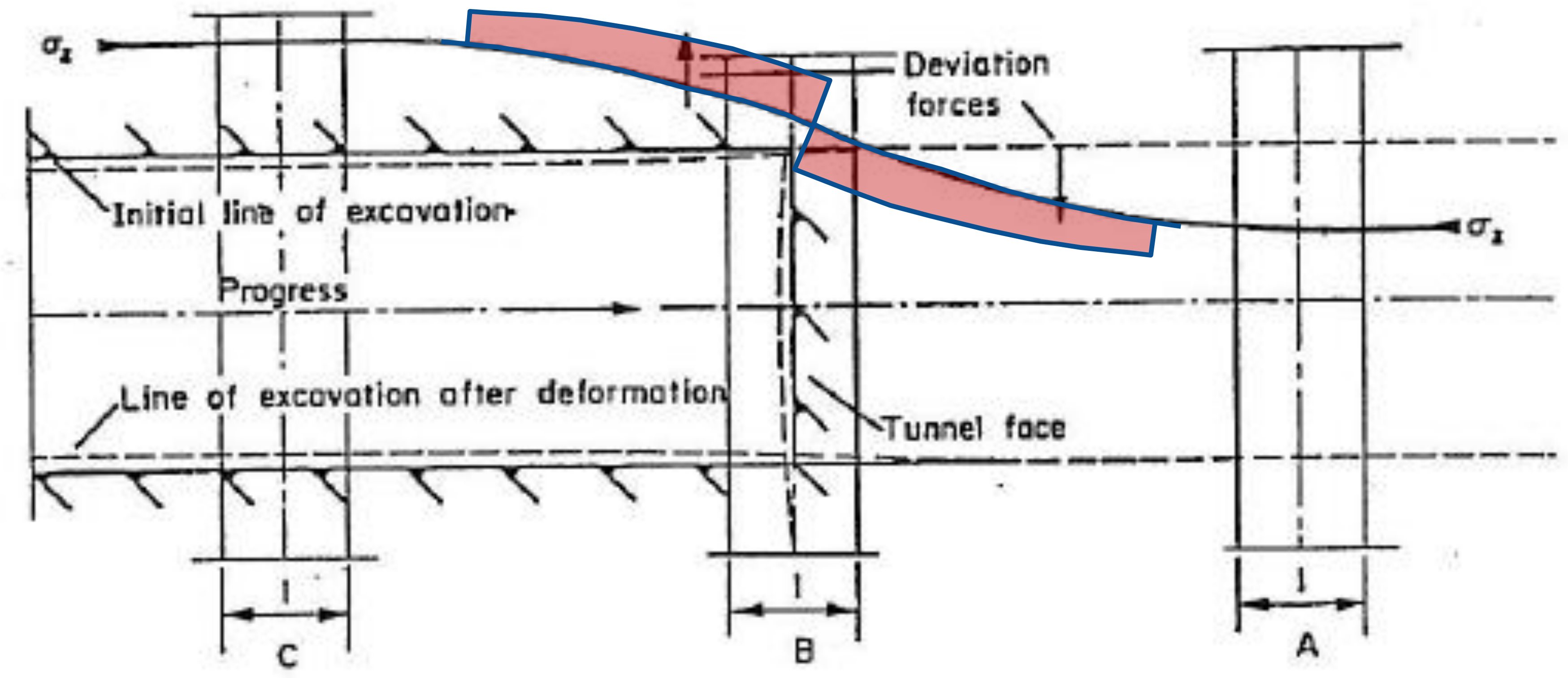
Jet grouting at the profile and fibreglass at the face

Fibreglass at the profile (grouted) and fibreglass at the face

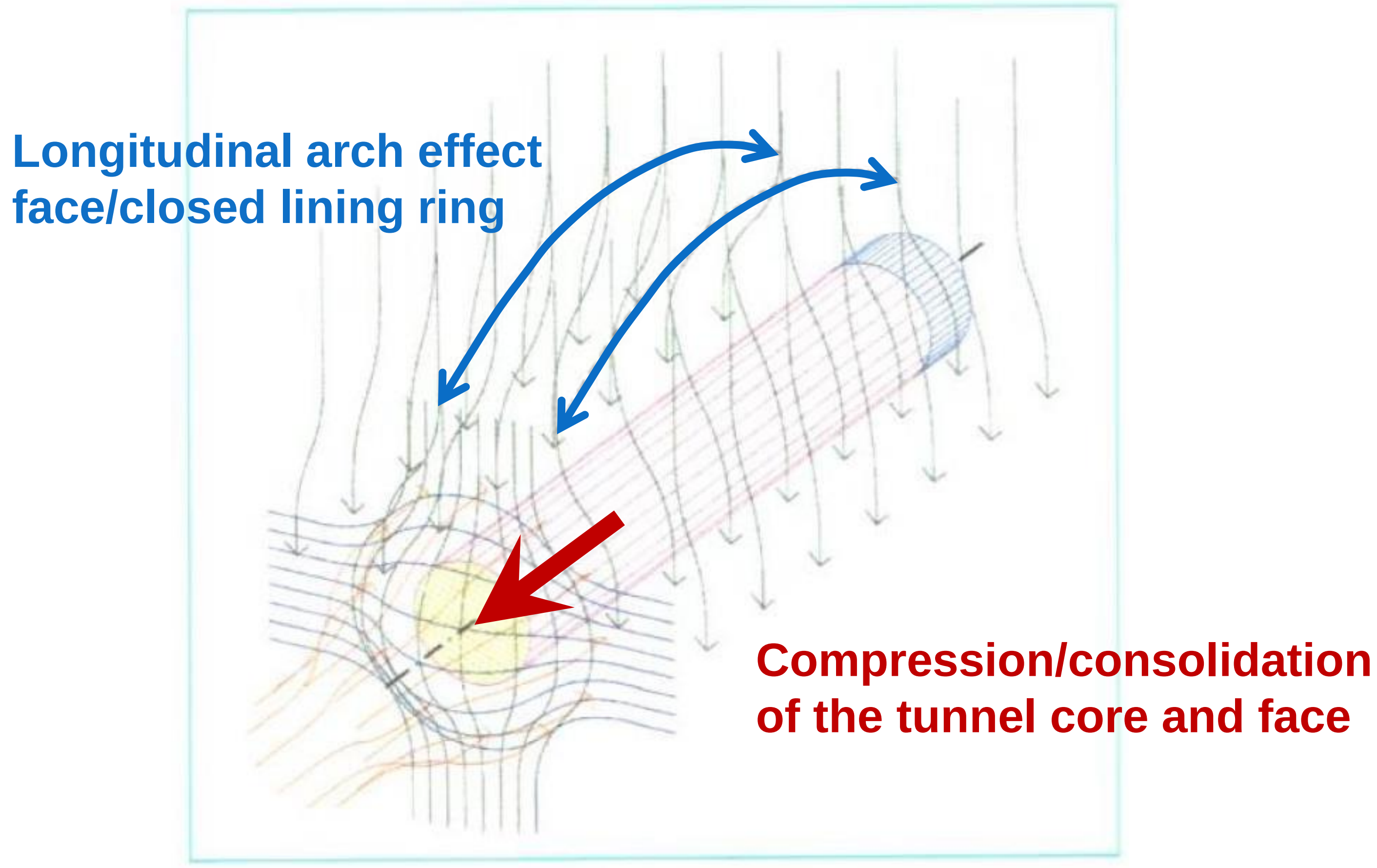
Grouting at the profile and at the face



ADECO-RS concept
based on the sole
face stability conditions - Therapy



Longitudinal stress deviation around the tunnel face (Lombardi, 1971)



Longitudinal stress deviation around the tunnel face (Lunardi, 2006)

TASK OF THE DESIGN in underground works
The limitation of the convergences of a underground cavity and other deformations and occurrences, by defining a wide pattern of hazard conditions, and designing a equally wide pattern of solutions for managing the behaviour of the opening towards the desired result …

HAZARD SCENARIOS

TASK OF THE OBSERVATION/SUPERVISION in underground works
… continuously verifying the whole process through a fitting monitoring system (feedback), thus observing the effect of the design and the construction on the behaviour of the opening, confirming the design decisions or evaluating the options for optimizing or adjusting the solutions to the actual situation.

MEMENTO-REMINDER
Along with this approach, don't stick to pre-defined philosophies or methods, by searching for looking into the problems with only their lenses,
but always evaluate the hazards and the best possible solution and solution pattern.

The judgment of the *"engineer"* in a wide sense and not only that of the *"specialist in computing"* should be adequately taken into account.
(G. Lombardi, 2011)

Thanks for your kind attention