

DEVELOPMENT AND BACKGROUND OF NATM

Wulf Schubert

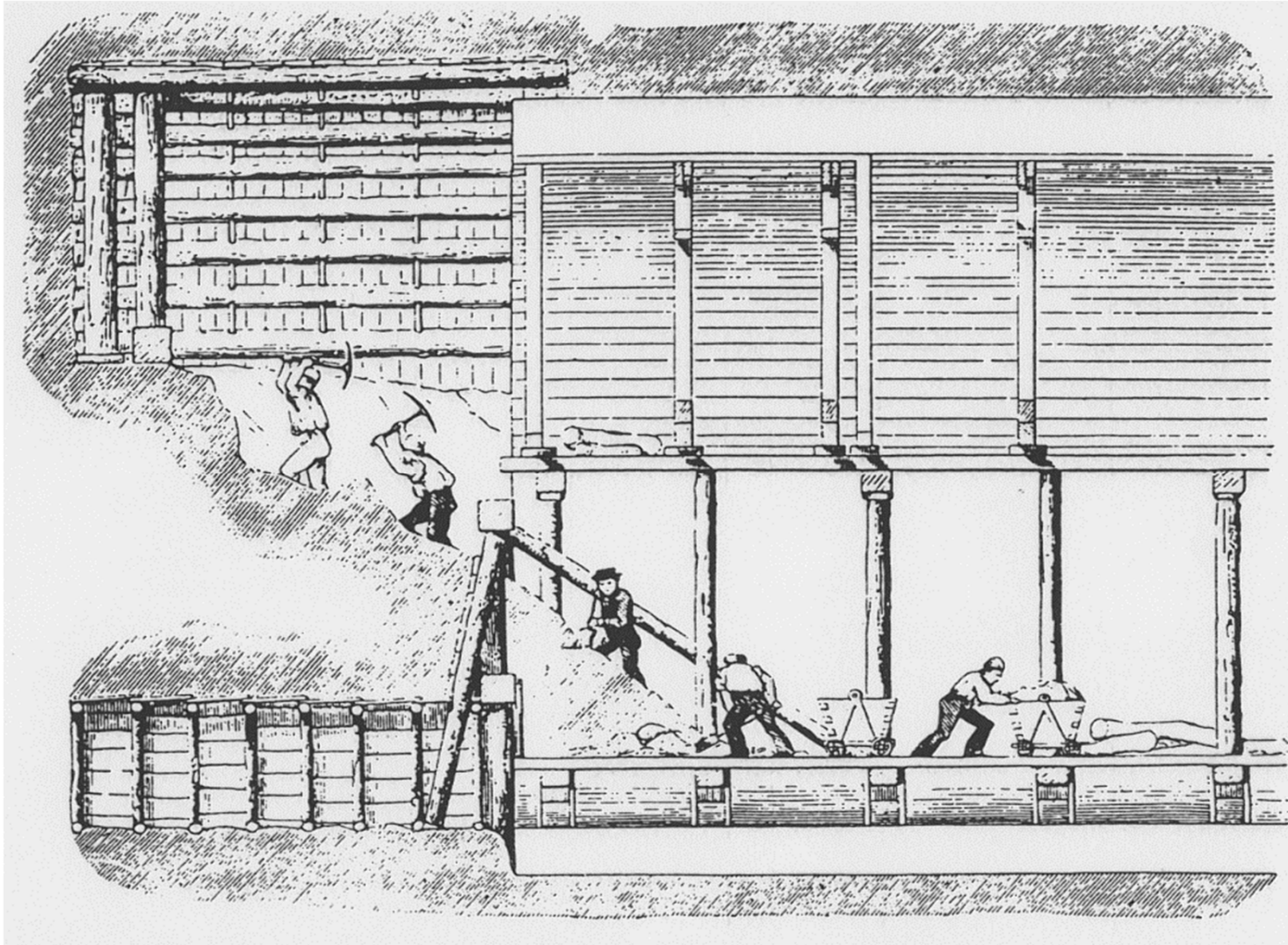
Graz University of Technology



TUNNELLING PRACTICE in mid NINETEEN HUNDREDS

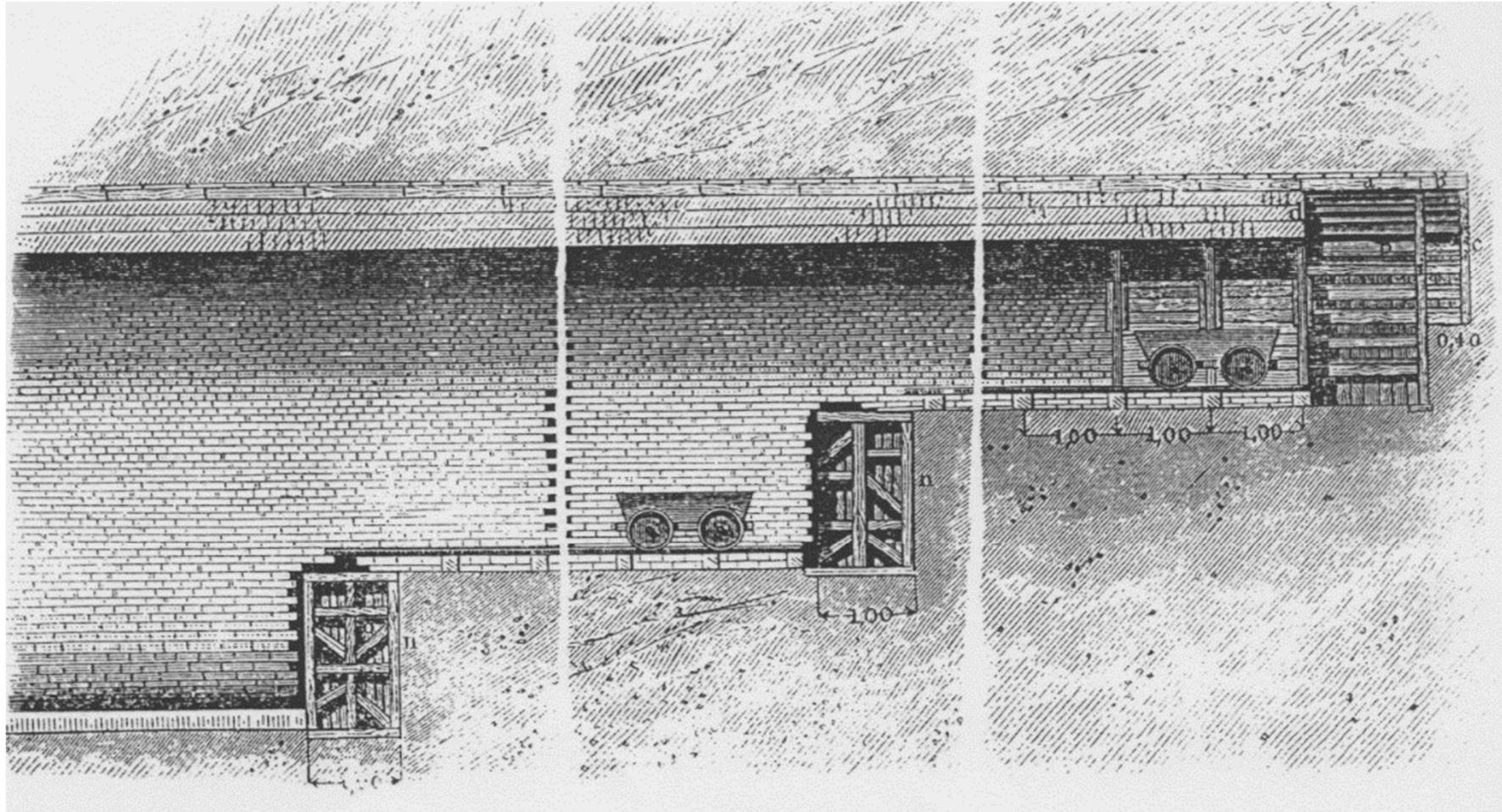
- Tunnelling in the 19th and first half of the 20th century characterized by partial excavation and predominantly timber support
- Small excavation sizes and timber supports required lot of manual work and prevented mechanization
- Frequent repropping of support caused disintegration of rock mass, loading the supports
- Theoretical background not really developed

DIFFERENT TUNNELLING METHODS 19th and 20th CENTURY



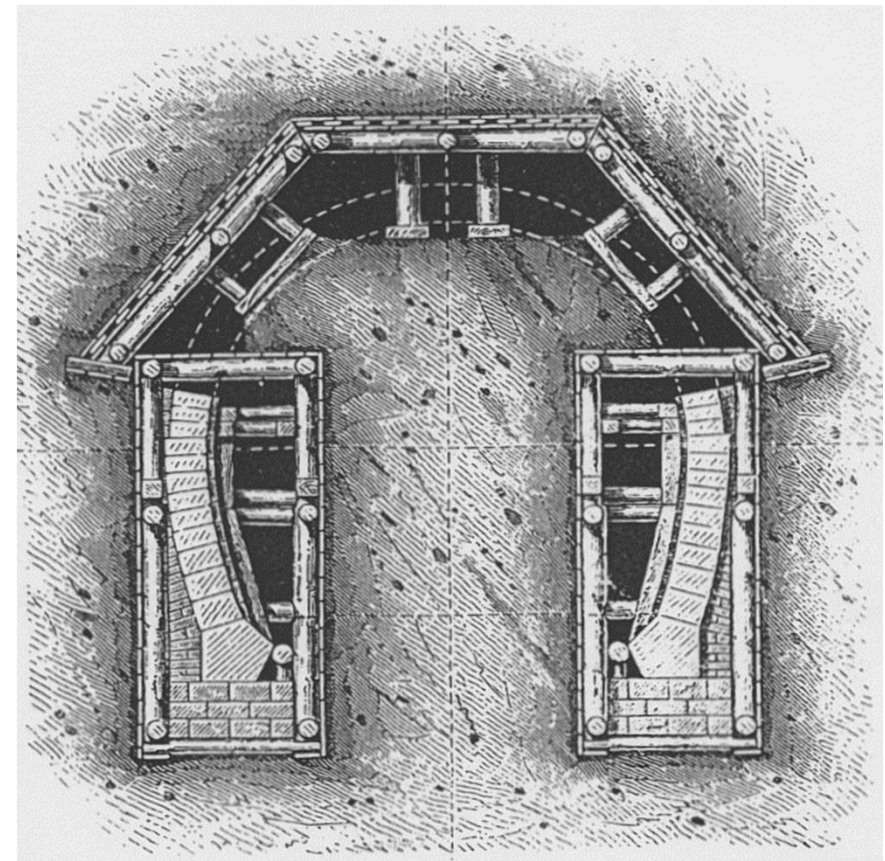
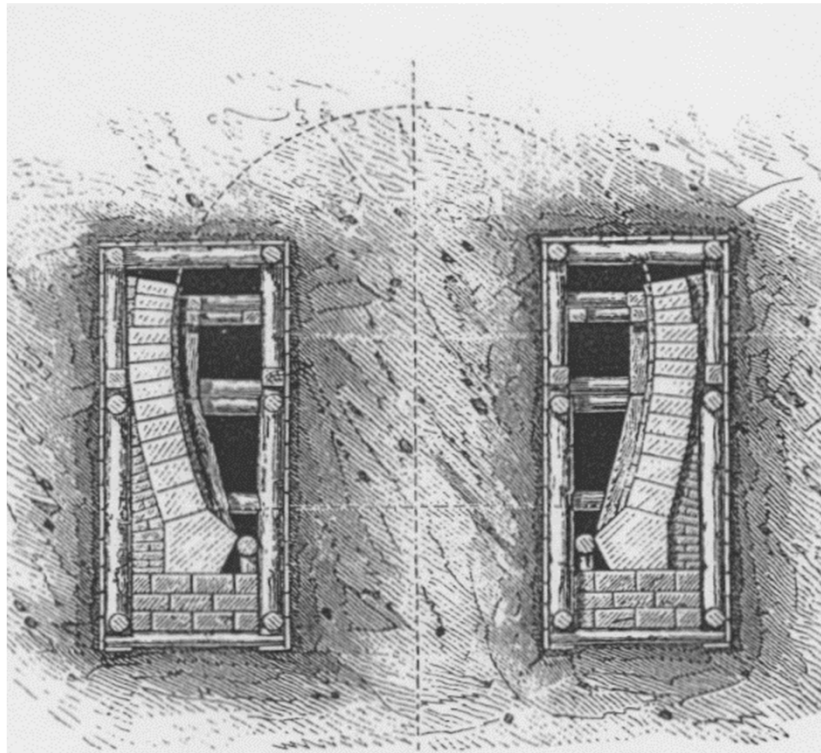
English tunnelling method

DIFFERENT TUNNELLING METHODS 19th and 20th CENTURY



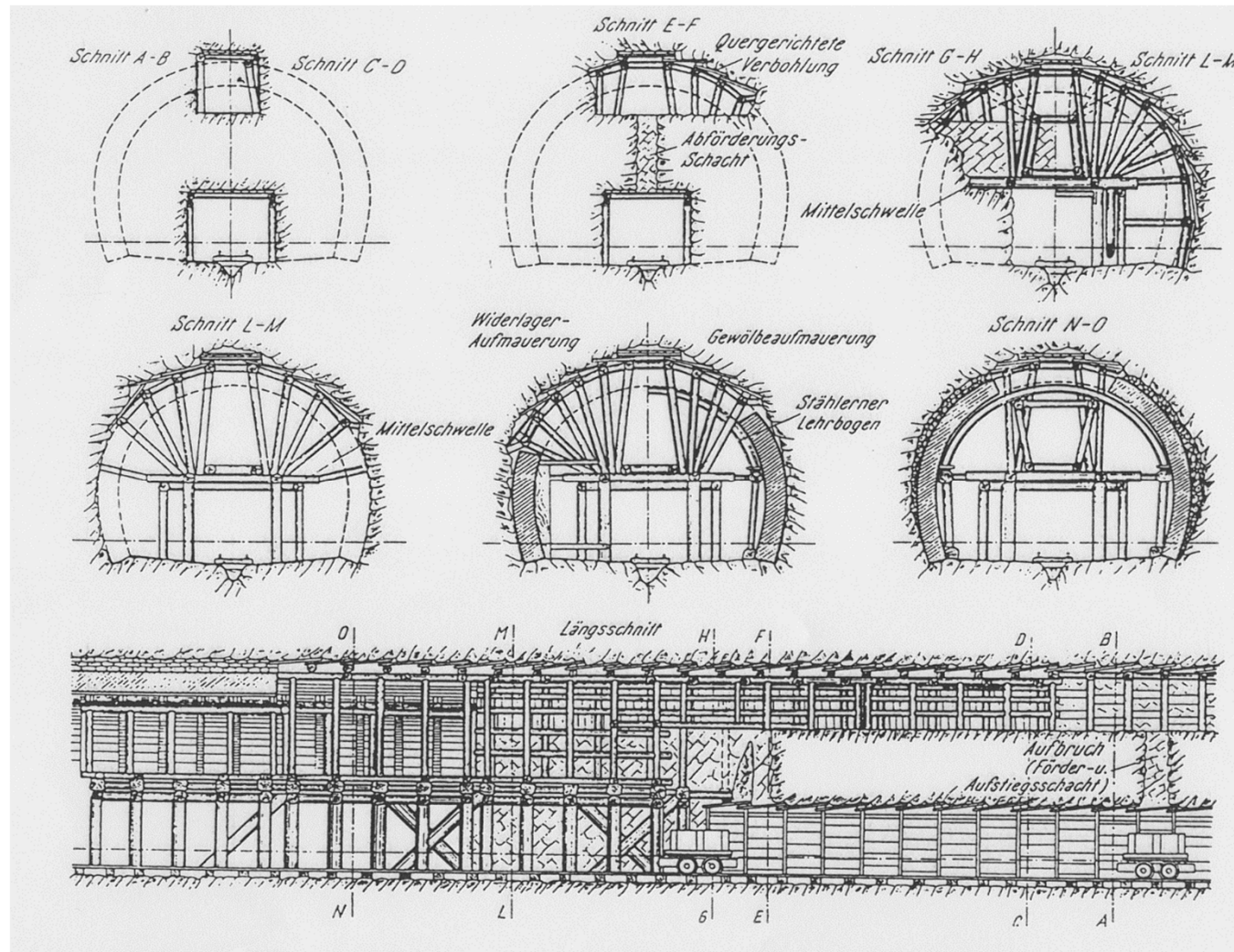
„Belgian“ tunnelling method

DIFFERENT TUNNELLING METHODS 19th and 20th CENTURY



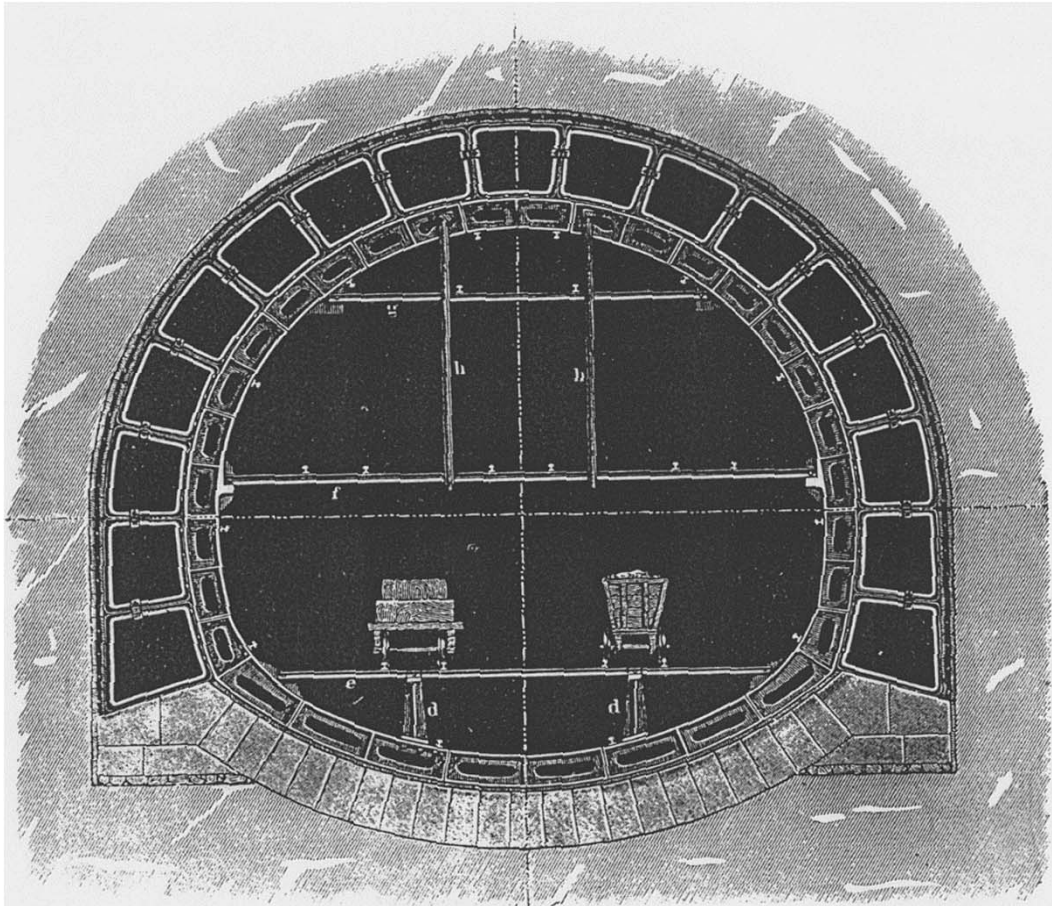
„German“ tunnelling method

DIFFERENT TUNNELLING METHODS 19th and 20th CENTURY



„Austrian“ tunnelling method

DIFFERENT TUNNELLING METHODS 19th and 20th CENTURY



Rziha's proposed steel frame support



Steel support with timber blocking

TUNNELLING PRACTICE in mid NINETEEN HUNDREDS



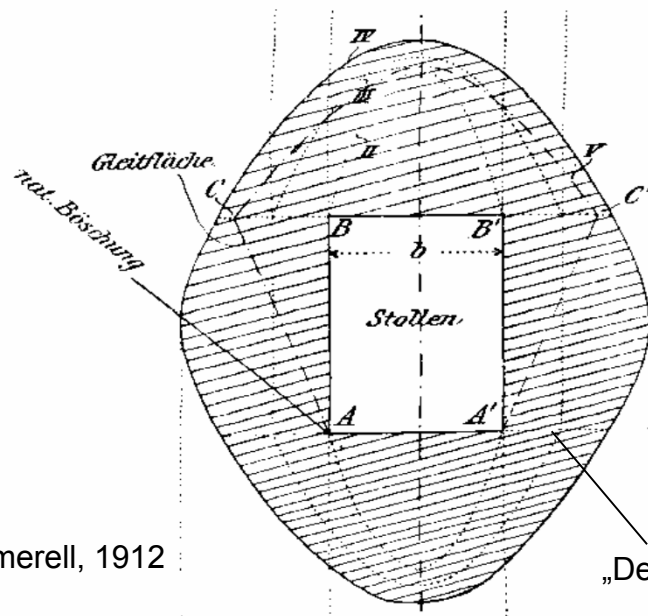
GKB, Austria 1951



South Link Railway Taiwan, 1986

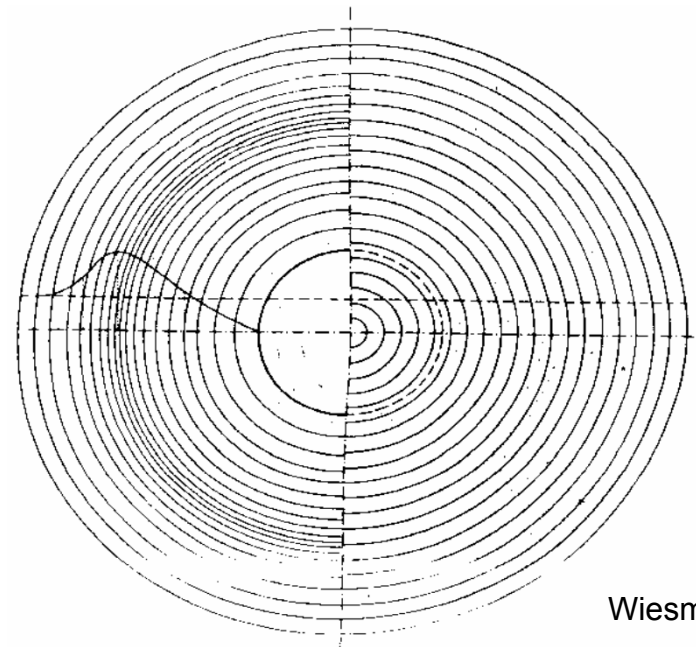
THEORY and LOAD CONCEPTS

- Over centuries tunnels had been designed and built based only on experience. Research into the mechanical processes started only around 1900. Many believed that a zone around the tunnel is completely destressed („destressed“ or „protective zone“)



Komerell, 1912

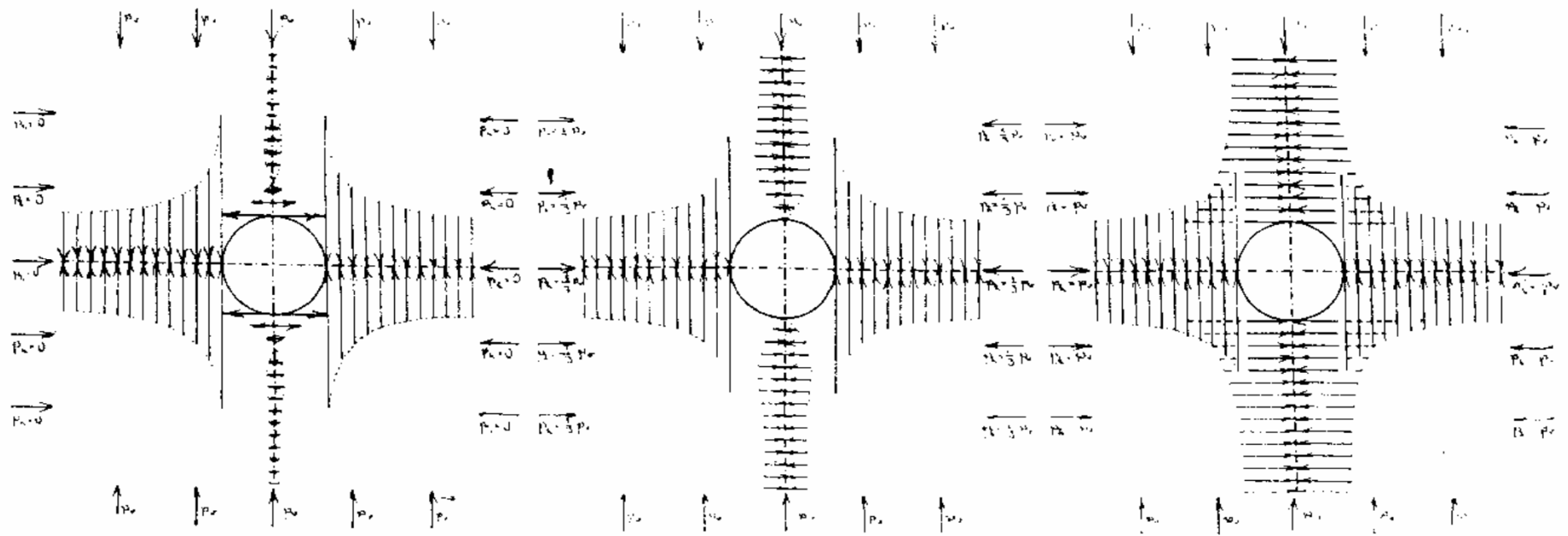
„Destressed“ zone



Wiesmann, 1909

THEORY and LOAD CONCEPTS

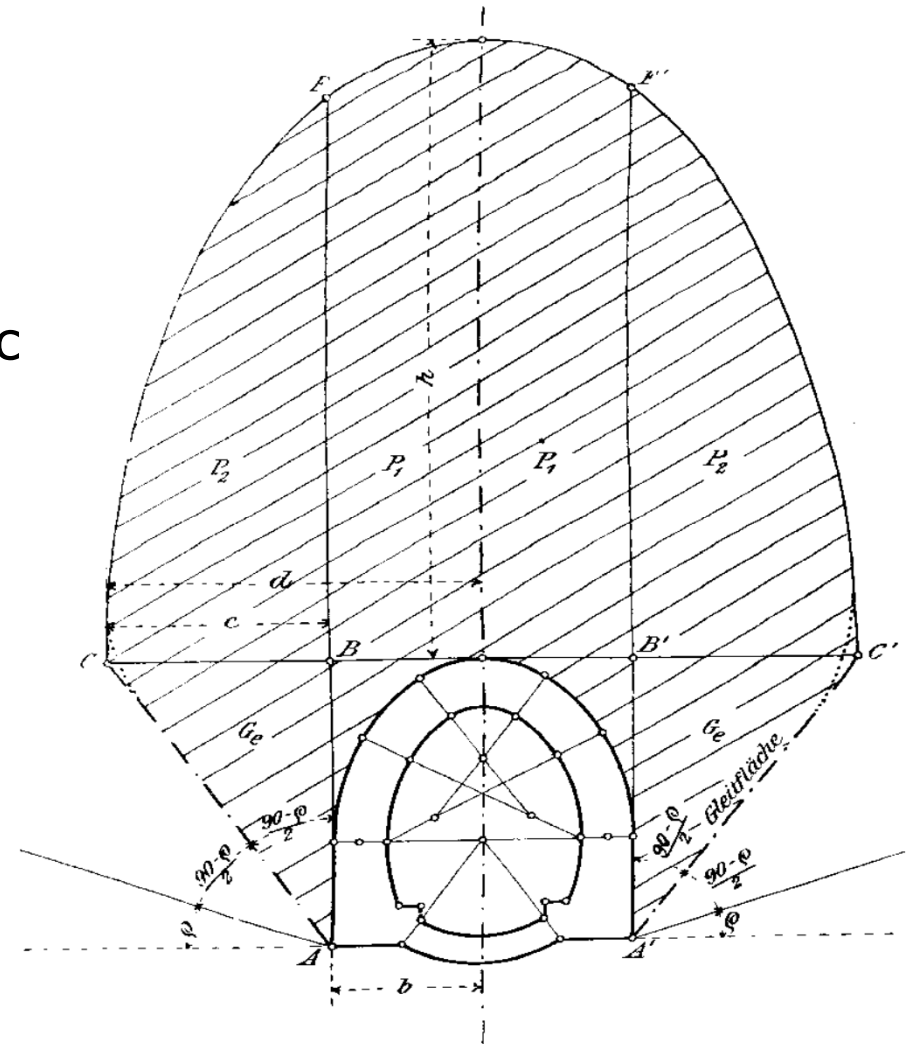
- Others found the theoretical solution, but practitioners did not use the findings for a long time



Leon & Willheim, 1910

TRADITIONAL TUNNEL DESIGN

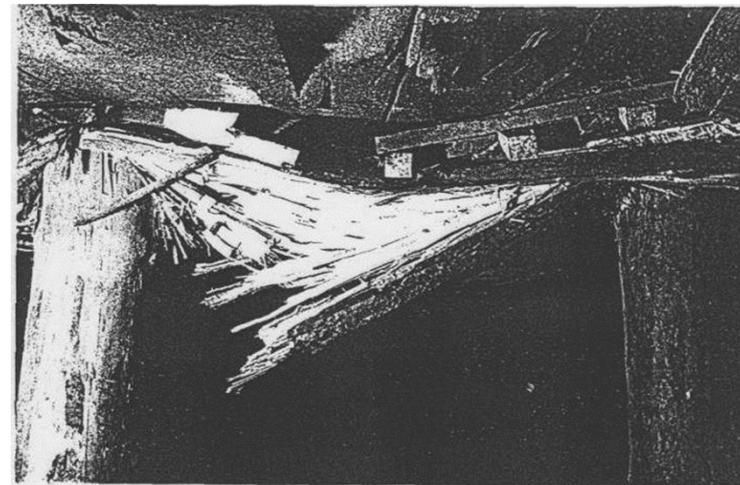
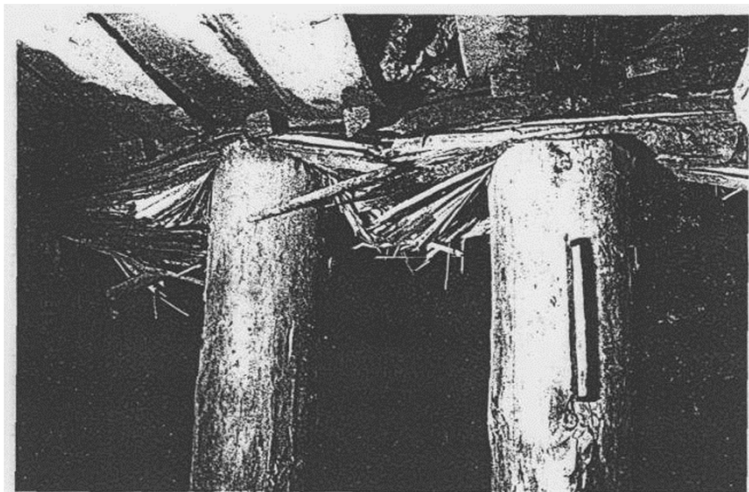
- Design of tunnel support generally based of hypothesis of dead loads
- Different behaviours, like „squeezing“, swelling, buckling, etc generally neglected
- Result thick and not adequate linings for many conditions



Kommerell, 1912

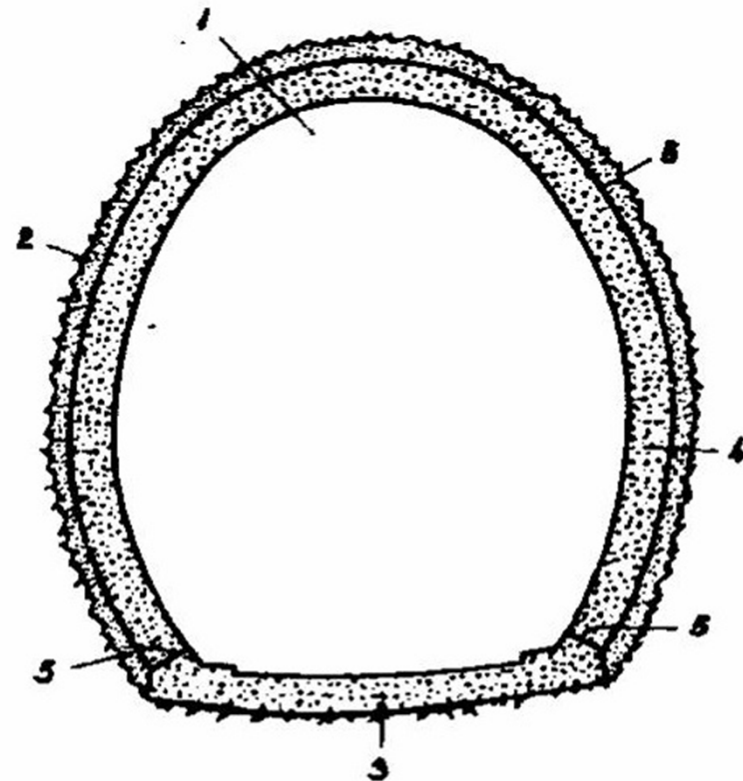
MAIN PROBLEMS WITH TRADITIONAL METHODS

- The poor contact of the supports to the rock, their low stiffness, and the frequent repropping during the different stages of excavation and support led to disintegration of the ground, thus loading the support
- A distinction between loads by loosened rock mass and by ground deformation (often referred to as „squeezing“) was difficult. Thus in „squeezing“ conditions linings were designed very heavy, often leading to their destruction



FIRST IDEAS OF NATM

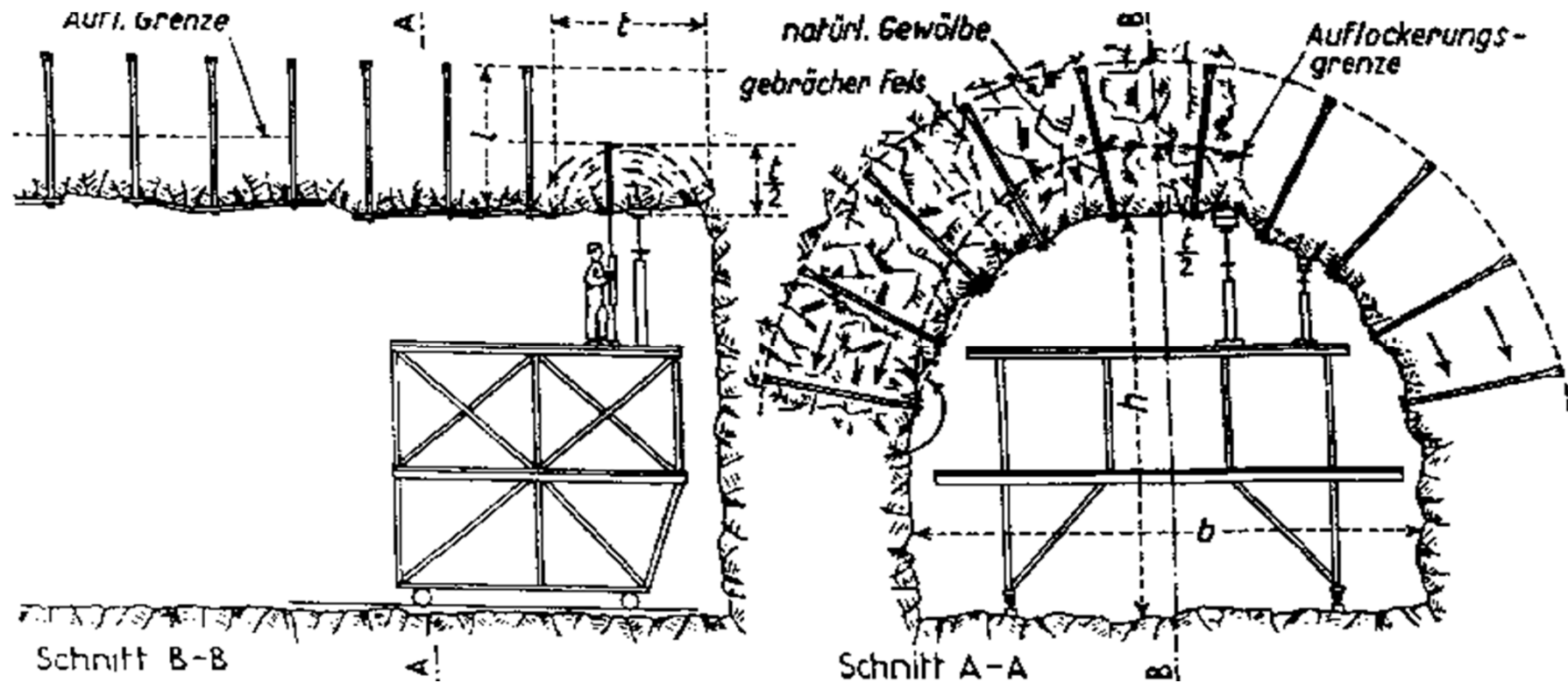
- Rabcewicz in 1948 patented a tunnelling method, which was based on a double concrete shell approach. Inner lining should be installed after deformations ceased
- Quickly installed primary lining should avoid disintegration and thus development of dead loads on lining
- Waterproofing between primary and secondary lining
- Determination of installation of inner lining based on measuring results



DEVELOPMENT OF SHOTCRETE AND BOLTING

- Although known and occasionally used since the 1920ies, the systematic application of shotcrete and rock bolts only started in the nineteen fifties. Use of roof bolting reported in the Forcacava HPP in Brazil
- Shotcrete helped prevent disintegration of the ground, which was a problem with traditional supports
- Rock bolts originally were used to fix single blocks, but soon systematic bolting was applied to reinforce the rock mass surrounding the tunnel.
- First application of systematic rock bolt and shotcrete support 1956 in Venezuela by Rabcewicz for highway and railroad tunnels. Systematic monitoring of deformations

SYSTEMATIC BOLTING TO CREATE CARRYING ARCH

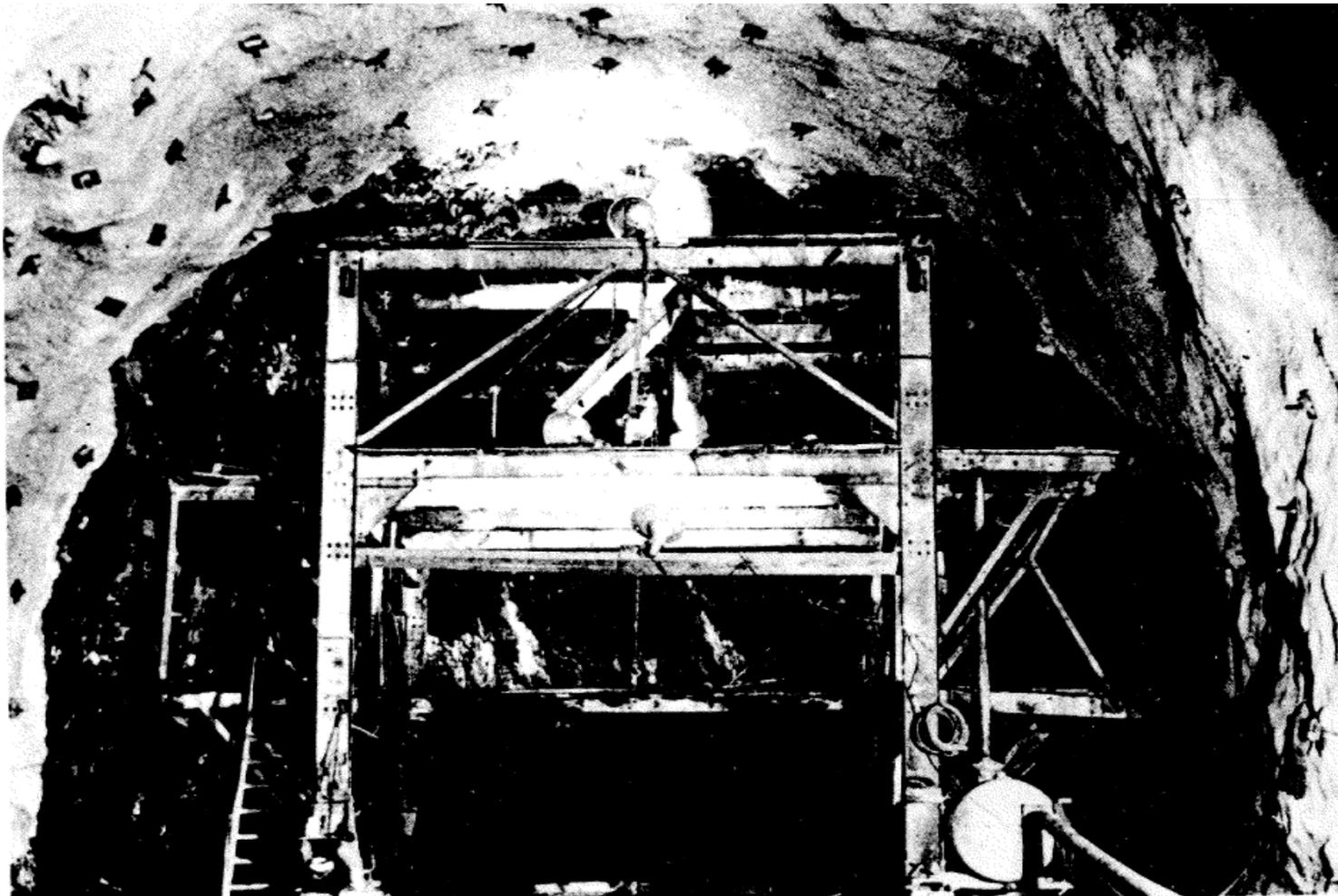


Rabcewicz, 1957

BASIC PRINCIPLES OF NATM

- Prevent disintegration of the rock mass, thus keeping its strength
- Use rock mass as far as possible to take additional stresses resulting from excavation
 - This implies that support should not be too rigid to allow load build-up in the ground
 - On the other hand deformation should be kept below the critical level, where disintegration (loosening) of the rock mass occurs
- Monitor the behaviour of the system to observe stabilization process and allow for adjustments of construction measures to ground conditions

FIRST SYSTEMATIC APPLICATION OF BOLTS AND SHOTCRETE

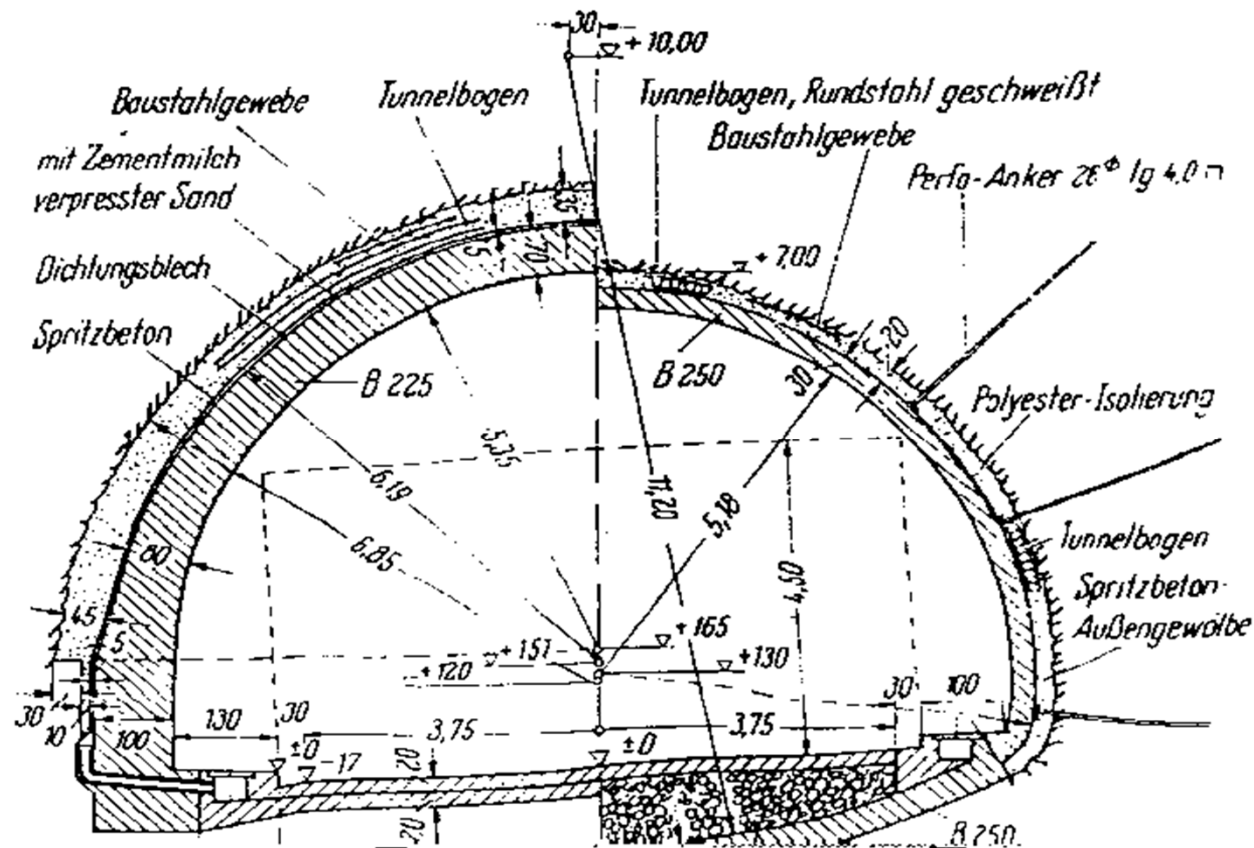


Tunnels La Cabrera, Venezuela, 1956

FIRST APPLICATION OF NATM IN AUSTRIA

ORIGINAL DESIGN (failed)

MODIFIED DESIGN (successful)



„CREATION“ OF THE NAME NATM

- Increased activity in underground construction, better insight into the mechanical processes, and the development of new support materials (bolts, shotcrete) have changed the practice of tunnelling in the second half of the last century
- Austrian engineers and companies have contributed a lot to the development of the new methods
- At the Salzburg Colloquium 1962 Rabcewicz created the name „New Austrian Tunnelling method“ to distinguish it from the traditional „Austrian Method“

FIRST EXPERIENCE

- Huge cost savings, higher progress, increased safety
- First projects with low overburden, but it showed that also difficult ground conditions relatively easy to handle
- International interest in the method increased; besides projects in Germany, also early applications in Japan and South America

FURTHER DEVELOPMENT

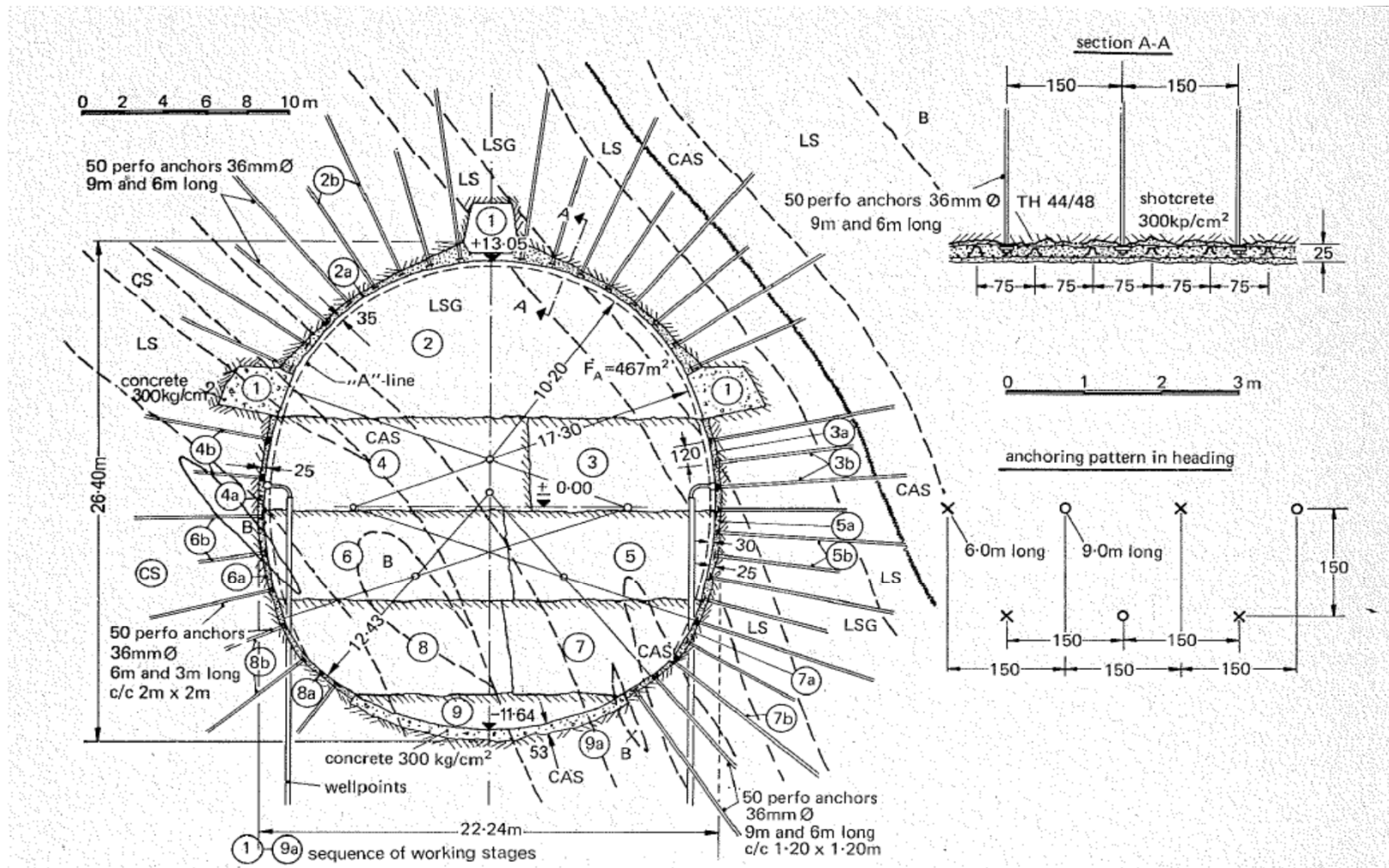
- The first regions outside Austria to adopt the method were South America and Japan.
- In the early nineteenseventies the method was also applied to tunnels with high overburden. A milestone was the Tauern freeway tunnel, crossing the Austrian Alps
- The succesful approach with shallow tunnels to close the lining as soon as possible to prevent loosening, could of course not be applied with high overburden in faulted rock.
- Large displacements forced to leave slots in the lining to avoid ist overstressing

EARLY MILESTONES



TAUERN TUNNEL, Austria, 1972

EARLY MILESTONES



TARBELA DAM PROJECT, Pakistan, 1973

MISSING ITEMS

- No accepted design rules
- Missing specifications, limited practice of miners
- Quality assurance of shotcrete
- Lack of appropriate contract models
- As clearly observational approach, organizational provisions needed to be established

FURTHER DEVELOPMENT

■ Design

- For the geotechnical design of tunnels a guideline has been established, with the aim to make designs transparent, consistent and audible
- The step-by-step procedure is risk oriented and focuses on hazard identification and mitigation; project specific requirements have to be met
- In-depth assessment of ground- and system behaviours required

■ Construction

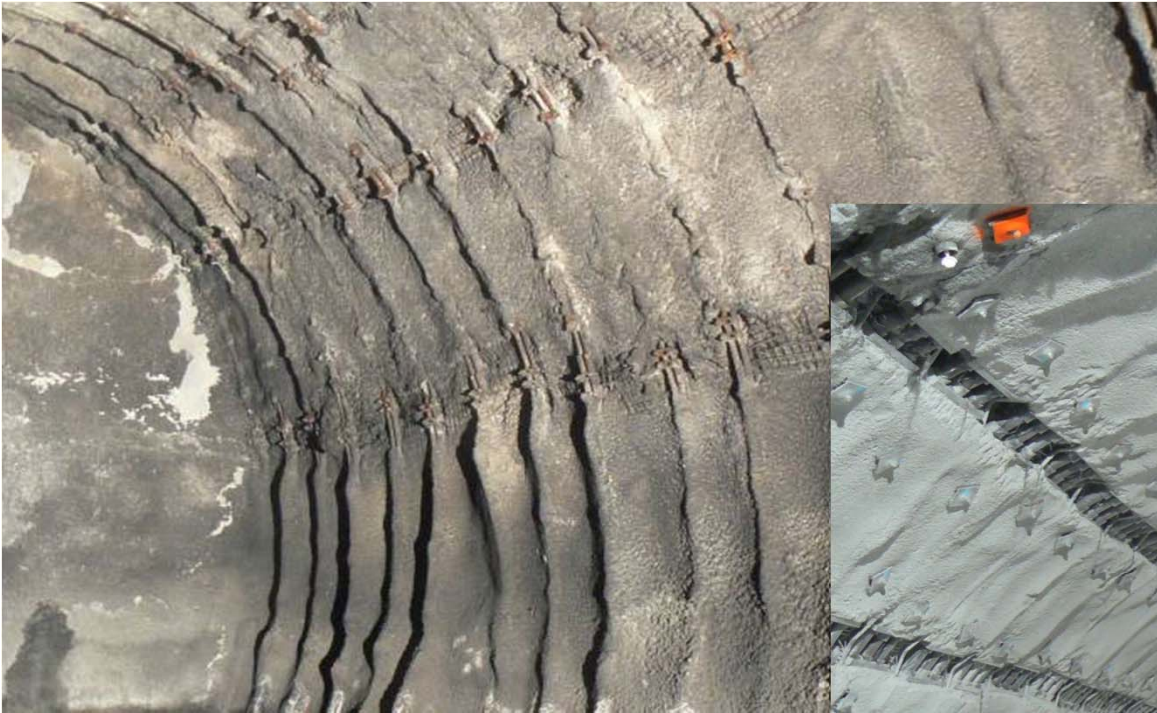
- Significant mechanization reduces required manpower
- Continuous further development of supports
- Costs of tunnel construction considerably reduced
- Accidents due to instability are practically zero (at least in Austria)

COMPARISON TAUERNTUNNEL 1 + 2

	Tauerntunnel 1 (1/1971 – 1/1974)	Tauerntunnel 2 (9/2006 – 7/2008)
Excavation time (both headings added)	53 months	44 months
Advance rate slope debris	1.7 m/d	2.9 m/d
Advance rate rock section	4.7 m/d	5.2 m/d
Excavation crew size	20 - 22	5 - 6
Max. displacements	≈120 cm	≈40 cm
Costs civil works	109 Mio €	108 Mio €* *

* Bid price. Considering inflation, costs of second tube are only 1/3 of first tube

Changes over the decades (example Tauerntunnel)



Tauerntunnel 1, Austria;
Use of open gaps in fault zone



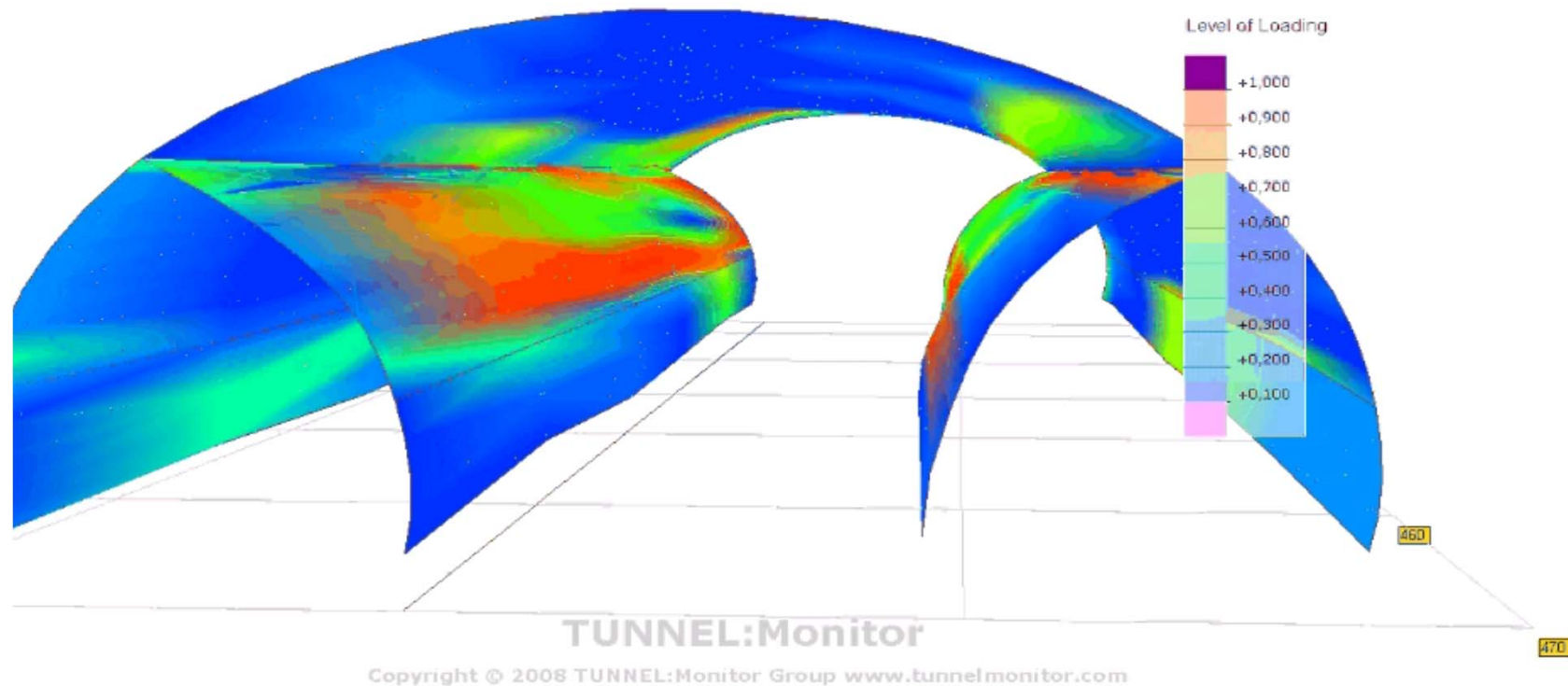
Tauerntunnel 2, Austria;
Use of ductile elements in the lining in fault zone

DEVELOPMENT OF MONITORING

- Monitoring was always considered important to control residual risk
- Further development of monitoring and evaluation methods actively promoted by owners and contractors
- Measurement of absolute displacements standard since more than 20 years
- This allowed developing advanced evaluation methods, which make tunnelling safer and more „predictable“

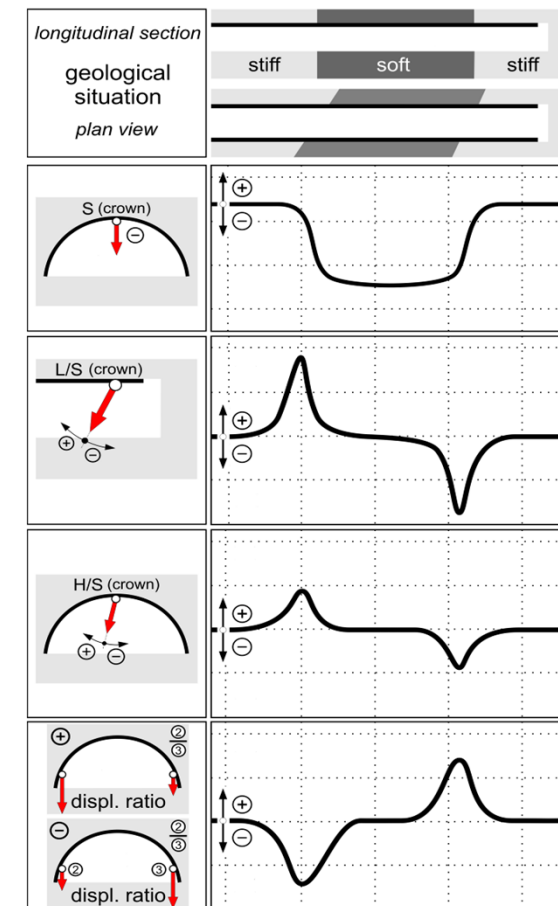
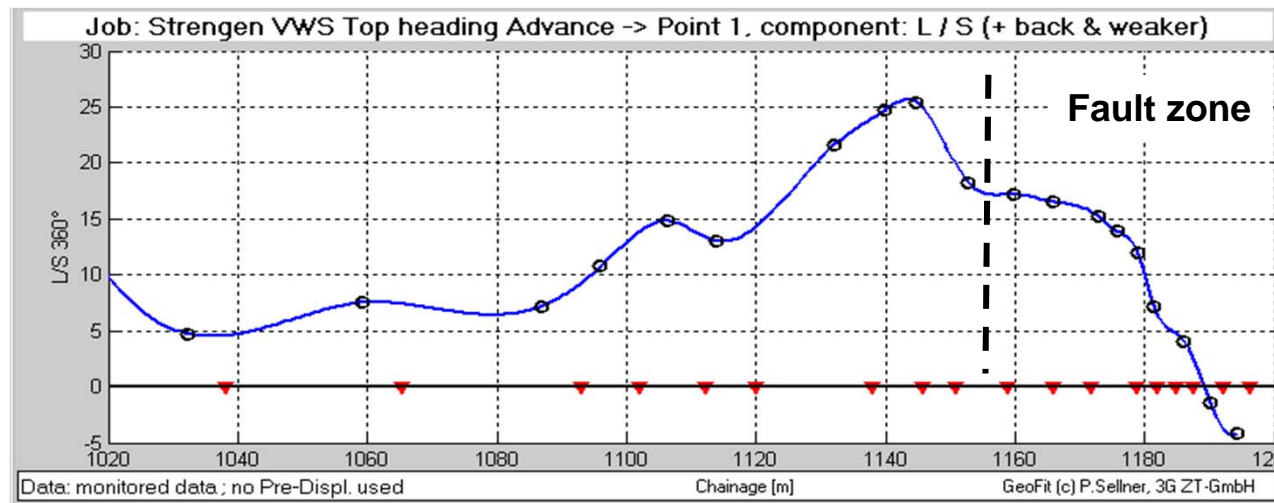
UTILIZATION OF LINING

- Advanced evaluation of displacement monitoring data allows assessing utilization of shotcrete linings



LOOKING INTO THE GROUND

- Using single or combinations of several displacement trends, ground structure can be assessed outside visible area



CONSTRUCTION CONTRACT

- In Austria risk sharing always was a principle
- Owner accepts geological risk
- Performance risk with the contractor
- Implies that owner needs to be competent, and actively participates in construction by providing competent staff on site
- Austrian Standard ÖNORM B2203-1 created to provide environment for fair compensation

SAFETY MANAGEMENT

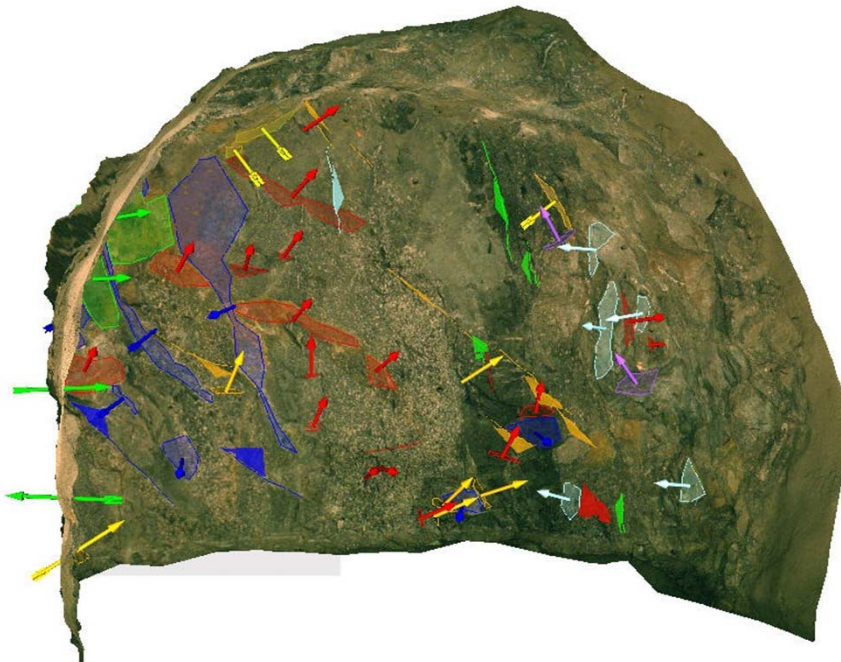
- Establishment of a geotechnical safety management plan has become mandatory
- Expected behaviour, as well as warning criteria and actions to be taken in case of deviating behaviour have to be defined for each section
- Geotechnical engineer on site assesses geotechnical conditions, evaluates monitoring data and supports site in decision making

SITE ORGANIZATION

- For successful implementation of observational approach site organization must be efficient
- Bureaucracy shall be minimum to allow efficiently adjusting construction to actual conditions
- Site must be staffed with competent personnel, having the decision making authority
- Besides technical competence, also social competence required

TEACHING + DEVELOPMENT

- Teaching, research and development at Austrian Universities focus on practical needs
- Owners and contractors willing to support development and also apply innovations on site



SHARING OF EXPERIENCE

- Exchanging views, freely discussing problems, sharing experience help further developing tunnelling



- Guidelines developed by representatives of all parties involved in the business contribute to further improving tunnel engineering and construction





CONCLUSION

- Advanced technology is a necessary precondition for successful tunnel construction
- Equally important is the creation of an environment allowing good and efficient co-operation, further development, sharing of experience, and fair contract handling as well as competence on all levels
- Only when all elements work together like wheels in a clock, efficient tunnelling with a minimum of risk can be achieved and the flexibility of the method utilized
- Always be open for new developments