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Quality Assurance and Safety in Highway Construction

Sécurité et assurance de la qualité dans la construction autoroutière

Sicherheit und Qualitätssicherung im Autobahnbau

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SUMMARY
The paper discusses the organisational and human aspects encountered in project management and on-site project supervision. Examples taken from five tunnel projects, with a total length of 6 km, and a highway-construction project (approximate length 30 km) demonstrate how continually changing geological and soil-mechanical conditions can be met in optimum form, in order to produce, with economies, safe and high-quality structures.

RÉSUMÉ
La contribution passe en revue les aspects humains et d'organisation pour la direction du projet et la direction du chantier. Il s'agit d'un tronçon d'autoroute de 30 km de longueur, avec 5 tunnels totalisant 6 km, dans des conditions géologiques et géotechniques diverses. Grâce à une organisation optimale, il a été possible de réaliser un projet sûr, économique et de qualité.

ZUSAMMENFASSUNG
Der Beitrag gibt einen Überblick über organisatorische und menschliche Aspekte der Projektsteuerung und örtlichen Bauaufsicht. Anhand von Beispielen über fünf Tunnel mit zusammen 6 km Länge und einem Autobahnbau von rund 30 km Länge wird gezeigt, wie auf die sich ständig ändernden geologischen und bodenmechanischen Bedingungen in optimaler Form eingegangen wird, um auf wirtschaftliche Weise ein sicheres und qualitativ einwandfreies Bauwerk erstellen zu können.

1. INTRODUCTION

As a rule, highways in Austria are planned and built by the Federal Road Administration. In May 1981, the National Council decided to establish "Autobahnen- und Schnellstrassen-Aktiengesellschaft" (ASAG) to accelerate the construction of priority road-construction projects. ASAG, a private corporation under Austrian law, has a small but highly efficient management staff. Consulting firms were commissioned with planning and supervising operations. ASAG extended a public invitation to interested consulting firms for the responsibilities of Project Management and On-Site Project Supervision (PRÖBA). 65 firms reacted to the invitation. My firm was put in charge of the following project components:

- Südautobahn A 2 across Wechsel Mountain
  total length of road 29.8 km, including more than 40 bridges, construction time 3 years

- Semmering Schnellstrasse S 6 from St. Marein to Oberaich
  total length of road 17 km, including several bridges and approximately 6000 m of tunnels in greatly varying geological conditions.

2. ORGANISATION

It must be borne in mind that extremely difficult geological conditions account for extremely complex terms of reference in project management and on-site project supervision, when including all bridges and tunnels and the structural facilities needed for the Federal Road Administration. It is recommended to resort to a matrix-like organisation, in addition to the linear organisation, just as there are staff and line functions in many industrial and military undertakings.

<u>Project Supervision - Linear Structure</u>	<u>Staff Functions</u>
Federal Minister for Public Works and Technology	professional support for
ASAG supervisory board	earthworks
managing board	soil mechanics
technical management/commercial management	tunnel constructions
departmental management	bridge constructions
	rock anchoring systems
	testing methods
PRÖBA business management	concrete technology
project supervision/ project management	bituminous materials
project supervision of project sections	quality standards
director	acceptance procedures
registered engineer	transfer to maintenance
engineer	
engineer's assistant	

Technical support for the construction sites is one of the tasks of a staff function. It is just as necessary to participate in meetings with the owner and the contracting firms, as it is to obtain all required information and to compile and update all documents, regulations, standards and decrees, as well as all relevant literature.

It may well be that one team member has both a staff and a line function, simply because team members vary in their qualifications, regarding specialized knowledge and acceptance from collaborators. When a team member is put in charge of duties that are of special interest to him, he may develop considerable motivating force. On account of his rural origin, an engineer's assistant, for example, who ranks at the bottom of the hierarchical structure, may be able to develop considerable professional knowledge on ecological engineering (e. g. using primarily such plants for landscaping purposes that have a water-draining and slope-stabilizing effect). When discussing the human aspects of organisational structures, we need to emphasize the fact that if a team member is capable of developing authority, regardless of the hierarchical constraints, and, thus, of making a valuable contribution to team performance, this will generate an overall positive impact.

Active Participants in the Construction Process

project control
- owner (client)
- design engineers

on-site project supervision
- contractors (working team consisting of several contracting firms)
- sub-contractors (specialized firms)

The following approach is recommended during construction performance, in particular when complex decisions must be reached under time pressure:

First of all, great care should be taken to involve all parties concerned in constructive cooperation. Each member of the team must have a sufficient understanding of the other members' problems, in order to select the technically meaningful option from a wealth of possible solutions. Good guidance through meetings is conducive to exploiting the potential technical resources of design engineers, consultants and the client's experts, but also of the contractor's staff, particularly of the specialized firms among the sub-contractors. At this stage, all contractual constraints should be disregarded.

Apart from, but in consideration of, the foregoing, all rights and commitments, time schedules, costs and responsibilities must be recorded in contracts. The contractual agreements require the written format and the preparation of all relevant drawings. It should be borne in mind, however, that irrespective of the efforts expended on the performance of a selected project, there is always scope for substituting the chosen approach by a better one.

3. QUALITY CRITERIA FOR ENGINEERING STRUCTURES

In the present context, quality means that a structure should be

a) functional
b) useful
c) safe.

Of course, a structure should also be commensurate with its environment and fit into the surrounding landscape.

In the planning of the structures which are discussed in this paper, it became apparent that they need not conflict with economy criteria. During performance it became evident that ecological engineering was required for many slope stabilizations and that careful re-cultivation of the landscape was indispensible, also for sound technical reasons.

One quality prerequisite consists in that the owner, i.e. the contract-awarding authority, not only specifies all requirements in a catalogue but also that he prepares a suitable in-depth project, where he can advance his opinion on quality in clear technical language. Any adjustment of the project to actual soil-mechanics and geological conditions must also meet a high standard - just like performance planning, since it is obvious that the building performance requires a high quality of planning.

The quality requirements for the building performance are laid down in the building contract and/or in the relevant standards, building regulations and statutes. Proper project supervision will make sure that the requirements are met. Suitability tests, tests during construction, and acceptance tests are the required means to this end. The same holds true for any documentation (of meaningful dimensions), since it helps to demonstrate performance according to contract and serves as reference basis for subsequent maintenance jobs. Unfortunately, the submitted price is the only competitive device used among contractors in most cases. As a result, a contractor's performance will not always come up to quality expectations, for reasons of economy. In doing so, he will incur the risk of price discounts for inadequate quality and contractual fines. In general, however, owners and, subsequently, maintenance authorities are affected more by inferior quality, than they benefit from a price discount for inadequate quality. Any responsible project supervision must therefore apply the necessary foresight in providing all prerequisites at the construction site which preclude such situations.

There are three aspects to safety:

a) The safety of tunnel driving crews and of workers below slopes exposed to slip hazards.

b) The safety of structural measures; this includes not only the prevention of failures of individual building components but also the hazard of above-ground collapses, or the impact of slope creepage or slippage, to which residents in the area are exposed.

c) Due evidence concerning the required safety of the finished structure.

Safety cannot be considered as an isolated quantity, it must always be viewed in the context of costs incurred thereby.

4. SAFETY IN TUNNEL CONSTRUCTIONS

The "New Austrian Tunneling Method" attributes special significance to safety in tunnel constructions. As is known, the resistance is reduced by incorporating the surrounding rock arch into the supporting structure. As a result, deformations are inevitable.

Nowadays road tunnels are built in areas which, a few years ago, would have been considered unsuitable for tunnel driving, on account of geological reasons. A wide range of technical decisions of great bearing, which also involve far-reaching financial implications, must be reached on site and with great expediency; as a rule, work continues 24 hours a day.

The "New Austrian Tunneling Method" is recognized today as being the leading technology in this field. Setbacks are usually suffered on account or bureaucratic obstacles. This means that, in many cases, the advantages of this construction method can be exploited only inadequately: there must be constant adjustment to actually encountered geological conditions, which cannot always be forecast fully, in spite of careful prospecting.

The author refers below to the southern tube of the Tanzenberg Tunnel (open for traffic since June 1985) and the two tubes of the Bruck/St. Ruprecht Tunnel, where construction work is nearing its completion.

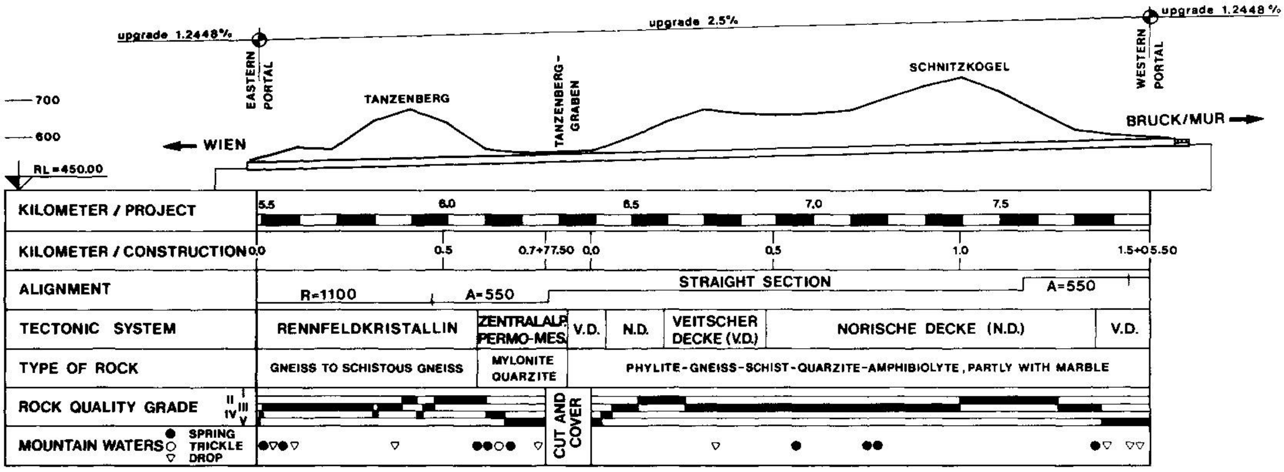
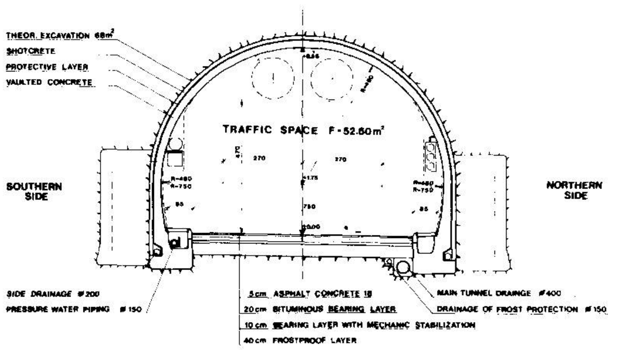


Fig. 1: Tanzenberg Tunnel, Southern Tube - Longitudinal Section



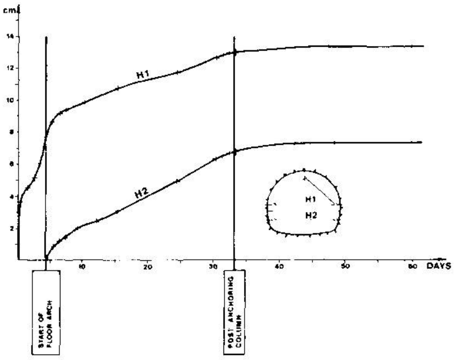


Fig. 2: Tanzenberg Tunnel, Southern Tube Standard Cross-Section with Bays

Fig. 3: Bruck Tunnel, Southern Tube Measuring Deformation at Station 750.0

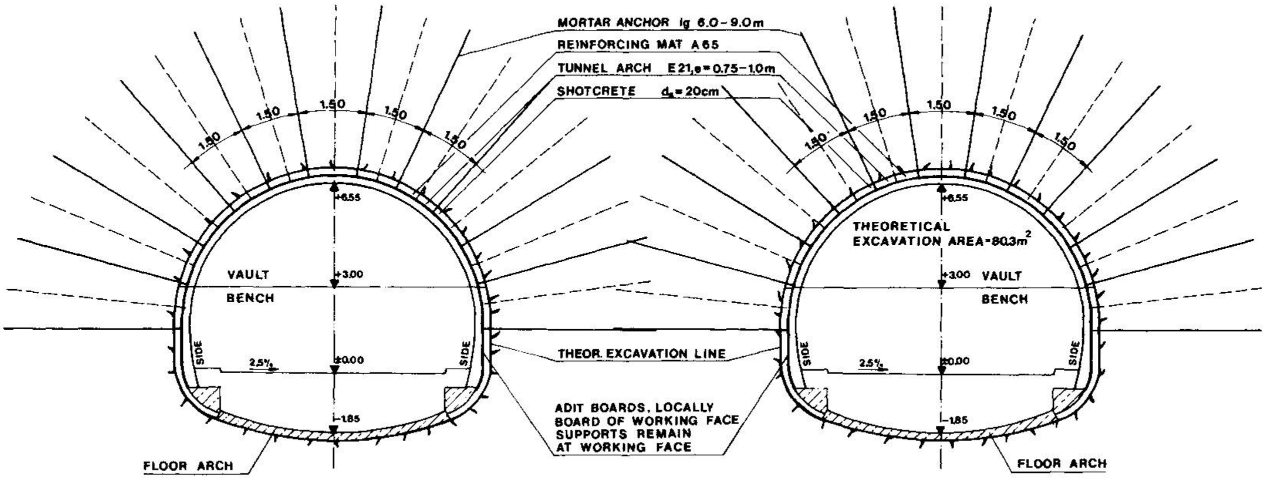


Fig. 4: Bruck Tunnel - Standard Supporting Means in Rock Quality Grade 5

The southern tube of the Tanzenberg Tunnel, driven at a distance of approximately 50 to 80 m from the previously existing northern tube of the Tanzenberg Tunnel, caused no major dificulties. Accordingly, the required rock resistance to finishing operations could be reduced, which, in turn, led to a reduction of costs for excavations and supporting means (shotcrete, reinforcing mats and anchors).

In the two tubes of the Bruck/St. Ruprecht Tunnel, which were advanced at a constant distance of 21.5 m, geological problems of considerable magnitude were encountered, since this tunnel is located close to the slope. The contractors tested deformations at intervals of 10 m, reporting the values continuously to the construction supervisor. Problems with the central column occurred first at station 300.0. Convergences H1 increased rapidly by 23 cm, the heads sank by 28 cm. This means that the central column (of graphite-like black phylite) could not absorb the forces. As a consquence, shotcrete thickness had to be increased to 30 cm, the anchors had to be reinforced with 9-meter pole anchors, and tube-excavation and floor-arch production had to be scheduled in optimum sequence. After consultation with the design engineer, anchors were also applied to the column, in order to increase the supporting effect, as in a girded column. When similar problems were encountered at station 700.0 - this time in heavily sheared black phylite - the same measures were taken. The convergence-value diagram clearly indicates the positive effect produced by the floor arch and the anchors of the central-column.

The following results were obtained at the Bruck Tunnel, regarding supporting means per tunnel meter in rock quality grade 5:

SUPPORTING MEANS	TENDERED VALUE	MEAN VALUE	EXTREME VALUE
shotcrete	4.28 m^3	4.34 m^3	6.46 m^3
reinforcing mat	67.7 kg	96.3 kg	192.7 kg
pole anchor	93.8 m	145.3 m	187.5 m

The two above examples indicate that expenditures have to be incurred in order to obtain the necessary safety standard. They also show that additional expenditures tend to stay within reasonable limits, although individual measures will produce major deviations.

rock quality grade	Tanzenberg Tunnel		Bruck Tunnel/St. Ruprecht Tunnel	
	tender	construction	tender	construction
2	495 m	558 m	0	0
3	1125 m	1318 m	1030 m	0
4	360 m	120 m	1684 m	388 m
5	293 m	287 m	716 m	3305 m
6	0	0	215 m	0
total length	2273 m	2283 m	3645 m	3693 m
costs for excavation and supporting means - mean value	AS 42,249/m	AS 37,883/m	AS 58,656/m	AS 72,787/m
	price basis July 1982		price basis April 1984	
deviation from contract sum	- 4.5 %		+ 7.4 %	

5. SLOPE STABILIZATION

Highway A 2 extends across Wechsel Mountain, which is supported by metamorphous rock series that were produced by physical and chemical transformation of a primary sediment. In an evolution of hundreds of millions of years, pressure, heat and hydro-thermal dissolution have led to the crystallization and scaling of minerals, which did not exist previously. These geological conditions give rise to a range of complex problems: the exposed rock structures could be worked with heavy equipment only; however, it became brittle and decomposed upon relief and access of atmospheric influences. Low-lying gliding layers caused large areas of instabilities in the slopes, which were cut up to levels of 130 m when constructing the highway. Tectonic-disturbance zones (mylonites) of greatly varying thickness can be found in all rock series. They mostly extend over longer stretches, causing a gliding effect in the slope locations. Apart from these natural gliding layers, it was our impression that over long stretches, the exposed rock material tended to revert the metamorphosis, i.e. to transform back into a primary sediment.

Accordingly, slope movement became apparent in many of the cuttings during excavation. In many locations, cracks (width: several decimeters) occurred at a distance of 200 m from the road. In other places, the movement could be detected only with the help of careful slope-indicator measurements. Slope indicators can also be used to determine the depth of the gliding layers and the speed of the gliding movement. In one location, 29,000 m^3 of material moved towards the road level, more or less suddenly, after the slopes had remained in balance for two months and after landscaping had begun.

Altogether, 50 slopes of cuttings were stabilized, 13 of which need continued observation after the construction has been completed, 5 of which at three-month intervals. In the case of one stabilization, it was decided to apply post anchoring.

Observations during cutting, and the measured values, served to produce project drafts, which were discussed at the construction site with all parties involved. The next phase was the implementation of the required extensive engineering projects for slope drainage and stabilization, which included wells, drainages, borings, piles, anchors, soil and rock nails, as well as rock and soil supporting structures.

For economic reasons, global slope-stabilization safety was increased by 5 % only, in most cases, since these measures entailed already considerable expenses. Localized stabilities, of course, were much higher. In particular, anchors (according to ÖNORM B 4455, class II/S2) and piles were built to produce the 1.7 safety factor, required by relevant standards. For technical reasons it would have been impossible to increase global slope stability to such a level!

Fig. 5: Loosened Rock Masses Gliding Off. Height of Slope: 50 m

Fig. 6: Crack Above Slope. Width of Crack: 20 cm, Distance to Road: 70 m

Figure 7 A Rock Mass of 29,000 m^3 Glides Off.