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# Tunnel excavation in cohesionless soils using excavation protection at the 'Bürgerwaldtunnel', Germany

## Réalisation du tunnel dans des sols non-cohésifs avec protection de la carotte à l'avancement au 'Bürgerwaldtunnel', Allemagne

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**ABSTRACT:** As part of the new „Hochrhein Autobahn A98“, which serves as a west-east connection between the „Autobahn A5“ near Weil am Rhein and the Swiss border near Schaffhausen, a twin tunnel (length approx. 1.350 m) has been designed through the „Bürgerwaldhöhenrücken“ to bypass the community of Tiengen. Only the northern tunnel has been constructed initially, which has to accommodate the dual traffic operation.

**RESUME:** Pour un allègement du trafic des voies de communication et des localités, un contournement de la ville de Tiengen est réalisé par deux tunnels, chacun d'une longueur de 1.350 m. Ce contournement fait partie d'une liaison ouest-est de l'autoroute future A98 entre l'A5 de Weil am Rhein jusqu'à la frontière Suisse à Schaffhausen. Dans un premier temps, la virole de tunnel nord a été réalisée qui est utilisée en phase provisoire en circulation en sens inverse.

### 1 INTRODUCTION

Tunnel construction always requires a quick reaction to cope with the locally encountered conditions and problems during the excavation process. For the realization of the project the difficult and non homogeneous soil conditions required special protection measures to enable tunnel excavation.

Two different protection techniques/methods have been used and are presented in this article.

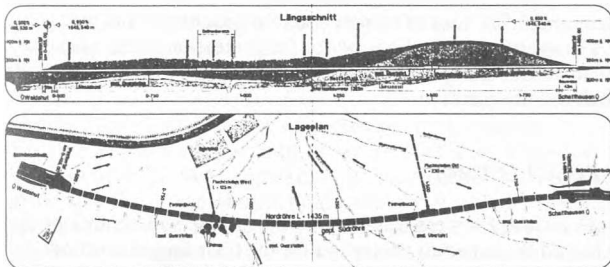


Fig.1 Layout

### 2 GEOLOGICAL CONDITIONS

The exploratory coreholes along the tunnel axis show extremely heterogeneous geological conditions.

Over a length of 800 m from the western side of the tunnel the encountered formations consist of soils of different densities together with inclusions of rearranged and sandless layers (Doline material) as well as cemented soil formations, i.e. of solid layers and lenses of „Nagelfluh“ with sporadically enclosed gravel and sand pockets.

Nagelfluh - a conglomerate - could reach a comprehensive strength up to 35 MN/m<sup>2</sup>.

No regular transition zones can be determined between the loose and hard ground formation.

From the eastern side of the tunnel mainly solid rock formations - Dolomite and Limestone - were encountered and the tunnel excavation could be performed by using the standard blasting method. The groundwater level was generally below the tunnel invert.

### 3 METHOD OF PROTECTION MEASURES FOR TUNNEL EXCAVATION IN SOIL FORMATIONS

Based on the different geological conditions two different techniques for the protection works at the tunnel excavation have been adopted.

#### 3.1. Grouted steel pipe roofing

The tunnel excavation within the gravel/sand formations containing interbedded Nagelfluh layers and lenses were performed under the protection of the grouted steel pipe roofing technique. Along the direction of the tunnel axis boreholes, equipped with steel sleeve pipes, length 13 m, were installed around the tunnel crown from the face and the soil formation was grouted with cement suspension. Spacing of the boreholes varied between 0,25 m and 1,00 m and were mainly dependant on the soil conditions exposed by the tunnel excavation and the first boreholes drilled for the protection roof, covering the next stretch of the tunnel excavation.

The main target of the grouted steel pipe roofing was the linking of the different Nagelfluh-layers and lenses by the steel pipes in the direction of the tunnel excavation as well as the permeation of the non cohesive soil by concentrated additional grouting operations through the sleevepipes.

#### 3.2. Horizontal Soilcrete® (Jet grouting)-columns vault

The use of horizontal Soilcrete-columns to protect the tunnel excavation was limited to cohesionless soilformations. The main feature of the Soilcrete-technique is the erosion and simultaneous mixing of the soil by a cement suspension under high hydraulic energy by means of rotating drill rods equipped with jetting nozzles at their tip, which are arranged perpendicular to the borehole direction. Jetting - i.e. erosion and mixing of the soil - takes place whilst the drill rods are retracted from the borehole.

The horizontal Soilcrete-columns - length 13 m - have been designed with a diameter of 0,60 m and a distance between the holes around the tunnel crown of 0,50 m thus allowing a overlapping of the Soilcrete-columns resulting in a firm vault protecting the tunnel excavation.

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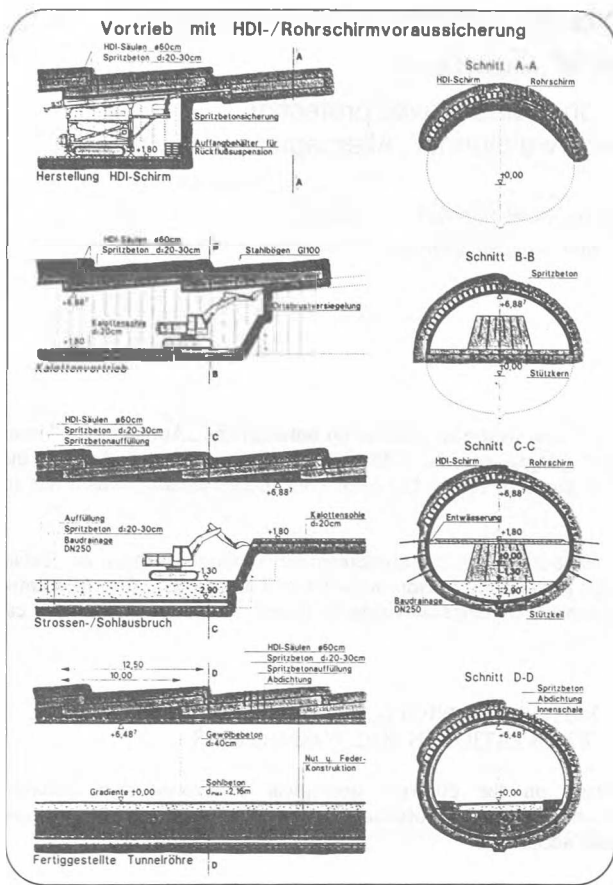


Fig. 2 Excavation principle

All boreholes for either method were located in a radial position around the crown of the tunnel and installed at an inclination of 1% in upwards direction from the horizontal position.

The tunnel excavation sections were generally 10 m in length and with a borehole length of 13 m this allowing an overlapping of the protection cover of 3 m.

The most essential condition was the availability of both techniques to cope with the encountered soil conditions during tunnel excavation at short notice.

#### 4 EXECUTION OF WORKS

To determine the tunneling protection techniques and the relevant working parameters field trials for the grouted steel pipe roofing as well as the horizontal Soilcrete-columns vault method were performed.

The trial fields were excavated and the results evaluated. According to the results achieved it was decided that for the first tunnel excavation section the horizontal Soilcrete-columns vault technique would be used.

Basic parameters of the Soilcrete:

Cement grout water/cement ratio = 1:1  
 Jet pressure = 400 bar (40 MPa)  
 Cement quantity/meter of Soilcrete column = 300 kg

The test results of the grouted steel pipe roofing solution indicated, that the Nagelfluh layers/lenses were well linked by the steel pipes. However the permeation of the non cohesive soil by cement grout did not reach the anticipated results, which led to the conclusion that the performance of the grouted steel pipe roofing requires careful monitoring and adjustment to the encountered soil formation.



Fig. 3 Excavated Soilcrete trial field

The excavation protection works for the western part started in the middle of June 1994 and continued until mid of July 1995. After completion of the 550 m tunnel length in sound rock formation from the eastern side without protective measures, the special protection works started in the transition zone between rock and soil formations using the grouted steel pipe roofing technique in October 1994.

All protective grouting works were completed by middle of July 1995 - the date the break through between western and eastern part of the tunnel took place. 260 m of tunnel length were protected by horizontal Soilcrete-columns vaults - consisting of 26 working sections with a total meterage of 10.800 m Soilcrete-columns plus additional 550 m for stabilizing the tunnel face and 300 m Soilcrete-columns for invert bench support.

Cement consumption for all Soilcrete works amounted to 4.000 tons.

54 tunnel sections - each 10 m length - have been protected by grouted steel pipe roofing, consisting of 31.800 m steel sleeve pipes and 1.200 tons of cement used for grouting of the soil.

The average working period for the protection shield of each 10 m tunnel section was approximately 3,5 working days with double shift operation.

#### 5 CONCLUSIONS

Both techniques were suitable for the specific soil conditions and achieved the expected protection for the tunneling excavation.

The anticipated problems in respect of soil collapses - especially in the areas where Dolines have been encountered and where 3 collapses occurred during the driving of the test adits, did not materialize.

Due to the increased portion of cemented soil formations along the tunnel line a larger number of grouted steel pipe roofing had to be performed - compared with the quantities originally planned.

The deformation of the tunnels have been constantly measured. The recorded measurements were always below the permissible limits.