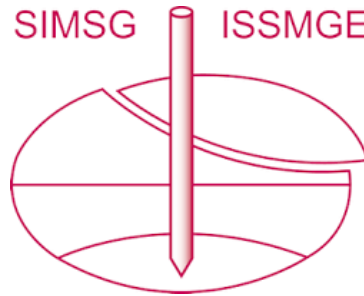


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# Dewatering Measures for Tunnel Construction

## Rabattement de la Nappe Phréatique pour un Tunnel

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### SYNOPSIS

A complex dewatering project for the construction of a railway tunnel in alluvial soils is described. Several dewatering systems are presented and the choice of the optimal solution is discussed with due account taken of the risks associated with the various schemes and possible effects on third parties.

### INTRODUCTION

On June 1, 1980, the new Zurich Airport railway link was inaugurated nearly 11 years after planning and design work started. The 6,4 km long, double-track link connects Zurich's airport Kloten (Fig. 1) with the main railway system of the Swiss Federal Railway (SBB) and brings the airport within reach of many major towns and metropolitan regions in Switzerland by direct, fast intercity trains. The construction costs for this link amounted to roughly 330 million SFr.

In 1970, Basler & Hofmann, Consulting Engineers and Planners, Zurich were commissioned by SBB for the planning, design and construction supervision of the 2,8 km long Hagenholz-tunnel which constitutes the central part of this railway link. The tunnel is situated beneath three minor hills known as Butzenbüel, Holberg and Hagenholz, with the overlying ground being 30 m to 45 m thick. Exceptions exist where the tunnel passes under a highway and the railroad Zurich-Kloten with ground covers of only 8,5 m and 12 m, respectively. The tunnel rises with a longitudinal slope of 1,04 percent from the underground airport station to the eastern tunnel entrance.

### GEOLOGY, GROUNDWATER-HYDROLOGY AND CONSTRUCTION PROCEDURE

The tunnel traverses three typical glacial soil formations: gravel deposits, moraines, and lacustrine deposits (Longo, 1978), where the gravel deposits have been preloaded by glaciers and therefore are dense to very dense. The gravel deposits are generally loose but occasionally form cemented conglomerates in places where the upper moraines are absent. Sandy and clayey-silty soil lenses are often present.

The groundwater table varies between 6 m (min.) and 14 m (max.) above the tunnel invert. Pumping tests in the borings indicated permeabilities of  $k=10^{-4}$  to  $10^{-3}$  m/sec in the gravel deposits, and  $k=10^{-6}$  m/sec in the moraines. The lacustrine deposits are practically impervious. Hence, the main problem of this project was the dewatering of the gravel deposits during construction of the tunnel. Preliminary estimates showed that a discharge of 30 to 80 l/sec had to be expected at the tunnel front, which would have made the tunnel construction without special dewatering installations impossible.

On the basis of the topographical, geological, and hydrological information at the site, it was decided to advance the tunnel by using a circular shield with a diameter of 11,46 m. However, because of the high sensitivity against settlement of some of the overlying structures (e.g. traffic routes, houses, utility lines and oil tanks) the shield was equipped with movable breasting doors (Fig. 3) to control the excavation of the soils at the tunnel front (Andraskay et al, 1977). Fortunately, the excavated soil deposits were in general more stable than was expected from the results of geotechnical subsurface investigations. The method proved particularly advantageous in controlling sudden breaches of gravelly soils or in retaining portions of the front during the loosening of hard portions by blasting.

The tunnel was divided into two construction sections to reduce construction time. In Section 7 the tunnel was advanced from the east downward (Frey, 1977). In Section 6 tunnel construction started from an intermediate point to reduce interference with the construction operations for the airport railway station at the western end of the tunnel (Müller, 1977). Construction started in April 1974

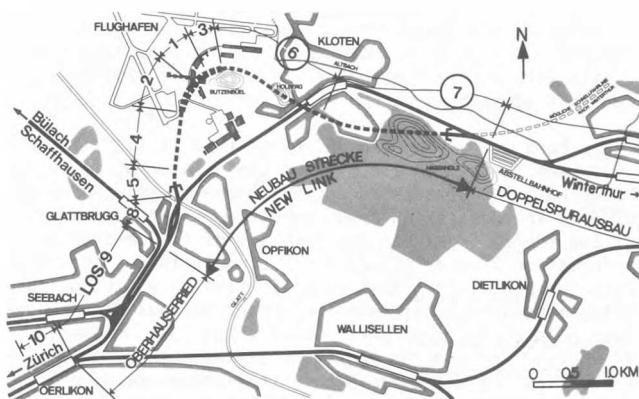


Fig. 1 New Zurich Airport Railway Link

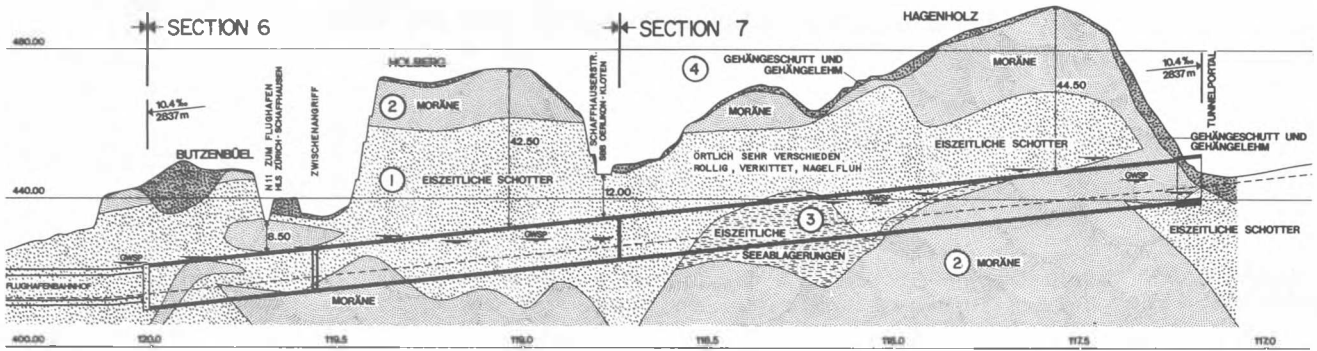


Fig. 2 Geological profile as known at time of bidding (① Gravel Deposits ② Moraines ③ Lacustrine Deposits)

On the basis of this information the following dewatering schemes (Fig. 4) were studied (Hofmann, 1974):

- Driving of tunnel under compressed air conditions,
- Lowering of the groundwater table with small-diameter vertical dewatering wells,
- Lowering of the groundwater table using a horizontal dewatering gallery, underneath the tunnel.



Fig. 3 Circular shield with breasting doors East portal

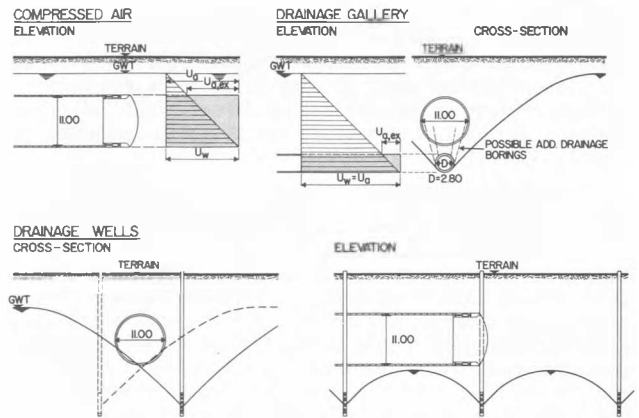


Fig. 4 Dewatering schemes investigated

and the tunnel break-through three years later in April 1977. The tunnel, excluding the railway track was completed on May 1978 at a cost of about 90 mio SFr.

DEWATERING SCHEMES

The tunnel traverses the groundwater basin Hard which borders on the groundwater basin Kloten in an area about 300 m north of the tunnel. Otherwise, the two basins are largely separated by a barrier (see Fig. 5) which runs in a SE-NW direction and consists mostly of moraines and lacustrine deposits. Because the city of Kloten receives its water from the groundwater basin Kloten, it was very important to determine the imperviousness of this barrier in connection with a dewatering scheme for the Hagenholz-tunnel during construction. After detailed geological investigations, it was concluded that a temporary dewatering operation along the Hagenholz-tunnel should have little influence on the yield of the groundwater wells of the city of Kloten.

Driving the tunnel under compressed air appeared rather difficult because of the large overpressure of 1 at existing at the tunnel crown. The anticipated leakage of air and the risk of a sudden blow-out in the gravel deposits with little overburden was considered too great for this dewatering method.

The second method has the advantage that it is flexible as far as the number and size of the dewatering wells is concerned. The dewatering operation can be adjusted according to the dewatering requirements during the advance of the tunnel front and can make use of the dewatering information already gained for a certain tunnel portion. Experience has shown that such "controllable" methods are often more economical than fool-proof methods which have been planned for the "worst-case" situation. However, the boring and pumping operation at the ground surface, as well as the extensive pipe installations to divert the pumped water would cause undesirable emissions for certain residents and property owners in Kloten. In addition, a cost comparison showed that the cost for this

system would most likely be substantially greater than those for a horizontal dewatering gallery. The basis for this cost comparison were pairs of small-diameter dewatering wells at a distance of 20 to 30 m along the entire tunnel section through gravel deposits.

The horizontal dewatering gallery has the advantage that the driving operation of the tunnel is not impaired. It also serves as investigation gallery and as recipient for the drainage water, especially for driving in falling line, because it is driven ahead of the main tunnel.

The bid documents for the tunneling work therefore specified a tunnel construction with shield, whereby the dewatering should be accomplished through a dewatering gallery with a cross-sectional area of 6 m<sup>2</sup> constructed ahead of the main tunnel. This gallery should be driven by using compressed air. Besides all the geological and hydrological information, the interested tenderers also received the design information, developed by the project engineer, which led to the specified construction method. The tenderers were encouraged to review this information from their point of view and to propose alternative solutions on the basis of their experience and the available construction equipment.

#### CONTRACTOR ALTERNATIVE AND ITS EVALUATION

To the surprise of project engineer and owner, a price-wise very attractive contractor-alternative was offered which accomplished the dewatering with large-diameter dewatering wells. Based on his dewatering experience in the airport region, the contractor concluded that the groundwater body in the area of the tunnel consists of a series of smaller groundwater basins (Fig. 5). By positioning large-diameter well groups at the deepest points of these basins, they could be depleted below the tunnel base. This dewatering has to be seen as an instationary process whereby the pumped water flow decreases with time due to the depletion of the basin. Eventually, the pumping operation will become stationary with a constant water flow to maintain the groundwater table at its lowered position. The contractor figured that about 40 of these wells of diameter 0,60 m and 0,90 m would be necessary to reach this condition.

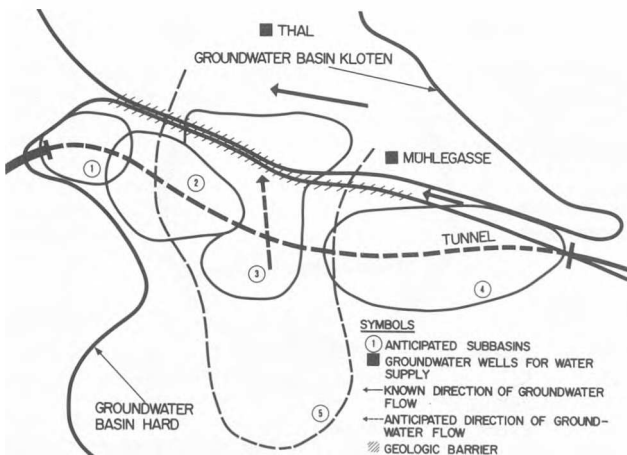


Fig. 5 Location of groundwater basins and subbasins

The geological and hydrological subsurface investigations were continued during the bidding phase, and revealed a rather irregular surface of the moraine and lacustrine deposits. This surface forms a series of "hills" and "valleys" which are covered by the gravel deposits. The main groundwater basin Hard therefore appears divided along the tunnel axis into smaller subbasins, a finding which confirmed the contractor's concept for the dewatering operation.

COSTS	3	PROBABLE COSTS POSSIBLE / MAXIMUM ADDITIONAL COSTS POSSIBLE / MINIMUM REDUCED COSTS
CONSTRUCTION DATES (MEASURE FOR EXCEEDING CONSTRUCTION DATES)	3	PLANNED EXPENDITURE ADDED / MAXIMUM EXPENDITURE REDUCED / MINIMUM EXPENDITURE
EMISSIONS	2	DEVELOPED / NON - DEVELOPED AREA
RISKS	2	ACCIDENTS, CONSTRUCTION FLEXIBILITY SYSTEM KNOW - HOW, DEPENDANCE ON HYDROLOGIC MODEL, IMPAIRMENT OF GROUNDWATER YIELD
EFFECTS ON TUNNEL ADVANCE	2	SUCCESS AND CONTROL OF DEWATERING DRAINAGE OF TUNNEL BY ADVANCE IN FALLING LINE, LOOSENING AND SETTLEMENTS IN REGION OF TUNNEL, ADDITIONAL SUBSURFACE INFORMATION
POSSIBLE CONFLICTS	1	WITH LANDOWNERS AT FAILURE OF PROCEDURE

Fig. 6 Main criteria for comparing drainage gallery and drainage wells (WW indicates weighting)

In view of the fact that project engineer and owner had proposed the use of a horizontal drainage gallery after long and intensive investigations, this scheme could not be abandoned before careful evaluation of all aspects of the two solutions. In the process of this evaluation the criteria given in Figure 6 were established to aid in the final decision making process. In the following paragraphs the criteria cost and risk are discussed briefly:

The costs were evaluated on the basis of the prices given in the bid documents whereby possible deviations in regard to additional or reduced costs were considered (see Figure 7). As far as the dewatering gallery is concerned, possible cost deviations were associated with the length over which the gallery had to be driven under compressed air. In addition vertical relieve borings from the gallery might have been necessary to drain groundwater from layers which are separated by impervious lenses from the dewatering gallery. The cost estimates for these borings were associated with substantial uncertainties. The uncertainties in estimating the cost for the large-diameter dewatering wells on the other hand arise from (a) the number of wells and (b) the pumping time required to control the groundwater. Additional costs were estimated in case the subbasins proved to be either not as clearly separated as was assumed originally, or substantially larger.

The risks of impairing the use of the groundwater basin Kloten were also evaluated. The additional costs for both solutions included the supply of water to the city of Kloten from other sources in case the groundwater table

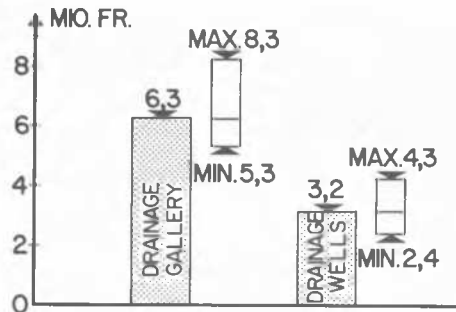


Fig. 7 Expected costs (shaded areas) and possible deviations

near the water wells would sink to intolerable levels. It should be considered that with the large-diameter well solution clean pumped water could be discharged again near the water supply wells.

A final analysis of the two solutions indicated that the large-diameter dewatering well solution proposed by the contractor was more economical and the owner decided to proceed with this solution.

The extensive geo-hydrological investigations which had been conducted in four stages up to this point included:

- 41 core borings with a total length of 1200 m,
- 2 subsurface investigation trenches,
- 30 smaller pumping tests in the borings,
- 3 large dewatering wells with pumping tests,
- 130 piezometer installations.

Although the costs for these investigations were substantial, they were only about 1,3% of the construction cost of the Hagenholz-tunnel.

## EXECUTION OF THE DEWATERING WORK

### Groundwater control and data processing

By decree of the Directorate of Public Works of the Kanton Zurich dated October 16, 1972, the SBB was allowed to lower the groundwater table during construction of the Hagenholz-tunnel below the tunnel invert. Certain restrictions had to be observed, however: The dewatering operation had to be limited to what was absolutely necessary, and had to be controlled at all times. After tunnel completion appropriate measures had to be taken to bring the groundwater level back to its original position.

Therefore a groundwater control program was developed in cooperation with the Consulting Firm for Hydrology and Geotechnics, A. Werner, Burgdorf. This program served the following two purposes: Firstly, the effect of lowering, i.e. the success of dewatering along the tunnel axis had to be determined for tunnel construction. Secondly, the groundwater surface was monitored over an extended area to check the overall performance and possible effects on groundwater usage during tunnel construction. The program consisted of:

- A grid of 130 piezometer installations,
- Periodic, generally monthly, groundwater table measurements in all piezometers and water wells since January 1973. During major dewatering tests and during the periods of re-establishing the original ground-

water table the measurements were made in shorter intervals,

- Continuous measurements of discharge in the drainage wells as well as in the groundwater wells Mühlegasse and Thal,
- Chemical and bacteriological tests at selected measuring points,
- Planning of contingency measures in case of interference with the groundwater supply from the basins.

A computer program GEOHYD (Geohyd, 1976) was developed together with the consulting firm A. Werner to process the extensive data which was collected during this exercise.

One portion of the computer program was used to store, process and print the data from the 148 measuring points (piezometers and wells). During the period January 1973 to May 1978 about 10'000 water level and discharge data were processed and arranged in tables and graphs.

### Optimisation of the dewatering operation

The above-mentioned information was also used to optimise the dewatering operation. The aim of this optimisation was to lower the groundwater table below the tunnel invert with a minimum of dewatering wells and a minimum of pumping time. With the cooperation of the dewatering contractor it was possible to construct the dewatering wells gradually according to the dewatering requirements of the different subbasins rather than by drilling them all at once. For every subbasin, pumping tests were made for several weeks. The resulting groundwater table information made it possible to predict the size of the subbasins rather well.

The geo-hydrological information resulting from the pumping tests and the geometric data (i.e. location and depth of the wells and estimated size of subbasin) then served as input into another portion of the computer program GEOHYD. This latter program part allowed simulation of the groundwater lowering process, on the results of which the decision could be made if additional wells were needed to lower the groundwater table to the final, prescribed level within a given time during con-

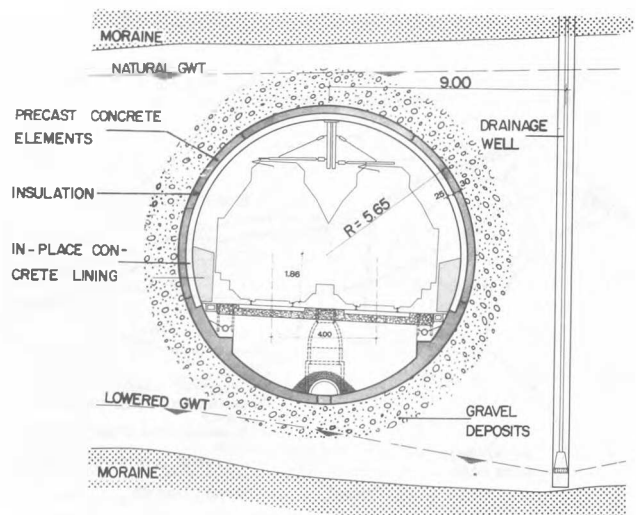


Fig. 8 Cross-section of tunnel with dewatering well

struction. If this proved to be the case, the program also allowed determination of the number and position of such wells.

The dewatering wells were generally installed near the tunnel axis, at a distance of about 9 m (Fig. 8). Whenever additional dewatering wells were necessary after the pumping tests, they could be located on the basis of the optimisation procedure described above. One dewatering well for example proved most efficient at a distance of 230 m from the tunnel, at the deepest point of a sub-basin. All wells had diameters (bore-hole/filter pipe) of 880 mm/520 mm (Fig. 9) with the exception of 6 wells with diameters of 670 mm/350 mm. The filter pipe consisted of a 4 to 6 mm thick steel pipe and was surrounded in the screen zone with a net having a mesh size of 1,4 mm. The gravel filter with grain sizes 6/12 mm was in some cases adjusted according to the surrounding soil conditions. The dewatering wells were also shocked by a device which was equipped with a high-pressure pump and a high-pressure water-air blower to clean the filter zone from sand and consequently increase the well yield. This cleaning equipment was activated at 0,50 m intervals along the screen zone until the pumped water contained less than 10/00 sand.

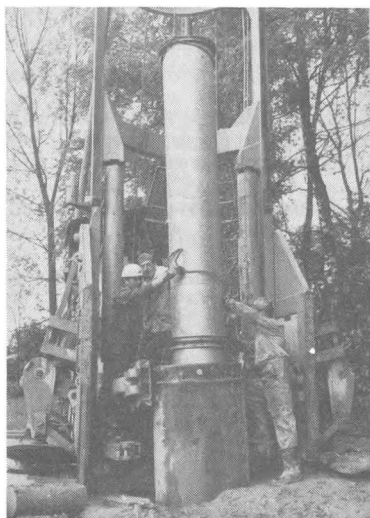


Fig. 9 Lowering of filter pipe

During the dewatering phase, the well discharge was on average about 1000 l/min, the maximum being more than 4000 l/min. After lowering of the groundwater table to the required level, only a limited amount of wells needed to be in operation. In this phase, the discharge per well was in the order of 60 to 200 l/min. A sizable pipe network about 5 km in length was needed to drain the pumped water into six sedimentation ponds and from there into the recipient surface water.

#### Experience with the operation

The success of this dewatering operation became apparent during tunnel construction. In contract Section 6, little or no groundwater at all was encountered during tunnel construction, and the excavation work was thereby in no way impaired. In contract Section 7, the tunnel portion in the moraine deposits was constructed without prior dewatering measures. The groundwater encountered in this tunnel section, with construction in a falling line,

caused only minor inconveniences. The total discharge at the shield was less than 5 l/sec on 86%, between 6 and 15 l/sec on 13% of all construction days. In the main gravel deposit section two pumping sumps 2 m below tunnel invert had to be installed in addition to the dewatering wells. The only major flow of water was encountered in a gravel lense which was discovered too late to be dewatered adequately. Here the discharge was between 25 and 30 l/sec for several days.

The gradual construction of dewatering wells proved to be very cost effective. Contract Section 6 (1300 m long) was dewatered with only 16 wells. The groundwater table in the gravel deposits of contract Section 7 was lowered with 6 wells. Only 20 of the 40 wells anticipated originally had to be installed, and 2 wells which were used for earlier pumping tests could be reused for dewatering purposes. On average the wells were 45 m deep, the deepest one being 65 m. The dewatering operation described above resulted in a total saving of approximately 1,0 million SFr., or about 30% of the initial contract sum for dewatering.

#### POST-CONSTRUCTION EQUALIZATION OF GROUNDWATER BASINS

As mentioned earlier, the original groundwater levels in the different subbasins had to be re-established after tunnel completion. The amount of groundwater draining through the tunnel therefore had to be less than the rainfall water added to the groundwater, which is for the area in question about 2000 l/min.

Railway operating conditions required an insulation with elastic foil (such as chloroprene or hypalon foil) above the railway track level over the entire tunnel length. Although it was clear that some insulation had to be provided also for the tunnel floor (invert), project engineer and owner nevertheless decided not to specify the most expensive insulation system with elastic foil in this case, but to have the contractor bid on several less expensive insulation methods.

With the aid of equalization tests (stopping of dewatering operation) it was possible to estimate for various completed tunnel reaches the drainage quantities, and hence to select the most cost-effective, appropriate insulation system according to the geo-hydrological conditions (Andraskay et al 1980). After some initial problems had been overcome, the entire tunnel invert could be insulated without detrimentally affecting the construction program. Details are illustrated on Figure 10. Of the total of 2760 m tunnel in question, 763 m needed chloroprene foil insulation of the tunnel invert; on 606 m the joints were sealed with a special packing mortar, whereas on 374 m grouting of the surrounding soil material proved effective. For the remaining 1017 m sealing of the invert joints with neoprene ribbons sufficed. These measures cost a total of 4,2 mio SFr., as compared to 9,0 million which would have been spent for elastic foil insulation along the entire tunnel floor; a differentiated sealing process and phased construction thus proved to be advantageous.

A further measure had to be provided in order to guarantee effectiveness of the natural barriers between the subbasin and thereby to prevent seepage along the outside of the tunnel. For this purpose, a total of seven grout curtains extending radially from the tunnel wall were provided. One year after the last dewatering well stopped pumping, the original groundwater table was established

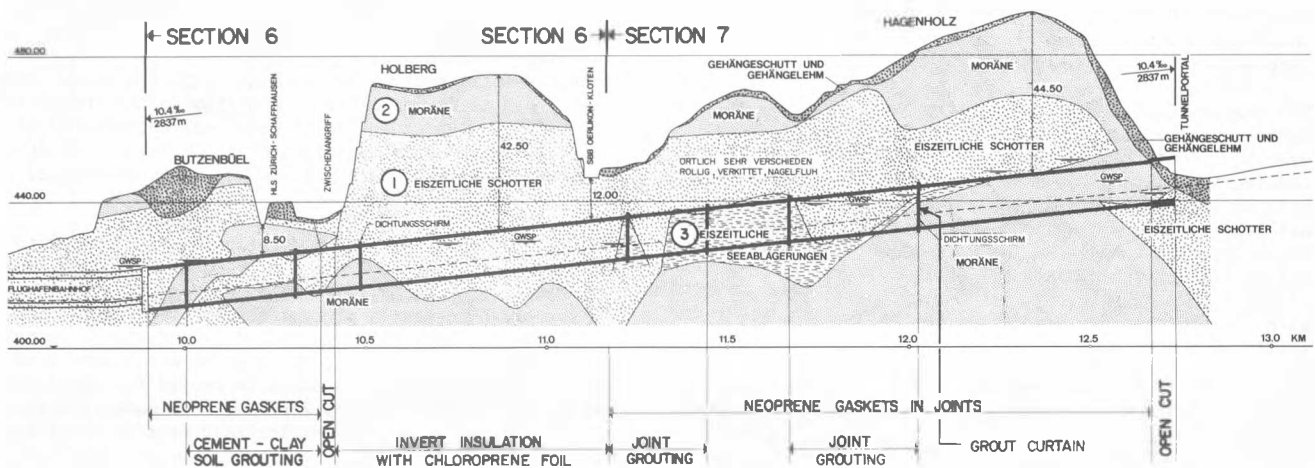


Fig. 10 Sealing and packing measures at tunnel invert

again; the drainage water collected in the entire tunnel averages about 1400 l/min since that date. At all surface points of high sensitivity against settlement precise levelling was performed. No settlements greater than 2 mm have been measured.

#### SUMMARY CONCLUSIONS

A complex dewatering project for the construction of a railway tunnel in alluvial soils is described. Several dewatering systems are presented and the choice of the optimal solution is discussed with due account taken of the risks associated with the various schemes and possible effects on third parties.

Staged geo-hydrological and geotechnical investigations, undertaken both before and during tunnel construction (e.g. careful monitoring of groundwater basins, extensive collection of groundwater and soil data, pumping tests) provided a host of data which were processed by computer.

Correct interpretation and utilisation of the results, cooperation between owner, project engineer and contractors as well as the use of latest construction technology made a successful and cost-effective dewatering operation possible, with optimal use of the dewatering wells, shortest possible pumping times and no negative side effects for third parties. The cost for final tunnel insulation could in the end also be reduced. Original groundwater conditions were re-established shortly after termination of construction.

#### ACKNOWLEDGMENTS

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#### REFERENCES

- Andraskay, E., Hagmann A., Hofmann E. (1977). Ausgewählte Projektierungsprobleme und ihre Lösungen bei der Ausführung des Hagenholtz隧NELS. SBZ Heft 20, 6-9.
- Andraskay, E., Fluder A., Hagmann A. (1980) Hagenholtz-tunnel-Abdichtung der im Grundwasser liegenden Tunnelröhre. SBZ, to be published.
- Frey, R. (1977). Der Hagenholtz隧NELS Los 7. SBZ Heft 20, 15-18.
- GEOHYD (1976). Darstellung und Auswertung geohydrologischer Messdaten, Handbuch 1. Auflage, FIDES Zürich.
- Hofmann E. (1974). Wasserhaltungsprobleme beim Hagenholtz-tunnel. Schweiz. Gesellschaft für Boden- und Felsmechanik, Heft. Nr. 89, 1-5.
- Longo V. (1978). Geologie des Hagenholtz隧NELS bei Kloten. Eclogae Geologicae Helvetiae, Vol 71, Nr. 1, 175-182.
- Müller H. (1977). Der Hagenholtz隧NELS Los 6, SBZ Heft 20, 10-15.