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Groundwater control in a deep road cut on Turku-Naantali highway

Le contrôle de la nappe dans une excavation profonde sur la route Turku-Naantali

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SYNOPSIS: The Turku-Naantali highway cuts for about 300 meters in a waterbearing till layer underneath clay in the crossing point of the Uusikaupunki railway. There is a small plan area of single houses on the clayey field about 150-250 m distance from the road cut. The construction of the road cut and the damages caused to groundwater lowering and environment based on calculations and measuring results are presented in this paper.

INTRODUCTION

The Turku-Naantali highway is a new road under construction situated in the south-western corner of Finland. The road is surrounded by clayey fields in the crossing point of the railway.

On the northern edge of the clay field situates the Polusmäki village founded mostly on watertight rock and thin till layers above bedrock. On the south side of the road cut situates a watertight area of bare bedrock diminishing the area of the groundwater basin.

The road cut was situated as far as possible from the plan area of single houses to make this alternative possible. Watertight concrete trough was considerably more expensive than compensations of the calculated damages. The nearest houses are on about 160 m distance from the edge of the road cut. The drainage level of the road cut is +2 at the lowest point near the pumping station. Original groundwater level is between +7 and +9 and the ground surface +8 - +10.

GROUND CONDITIONS

On the chosen road line the thickness of the clay layer varies between 2-6 m. In the surface is about one meter thick layer of dry crust. Dry crust is underlaid by very soft and sensitive clay. The shearing strength of the clay under dry crust is only 5-10 kN/m² and water content 70-90 %. Clay layer is normally consolidated and the modulus number m used in the tangent moduli method varies from 4.7 to 6.1 and the stress exponent β from -0.8 to -0.4 correspondingly. The coefficient of vertical consolidation is between 0.06-0.15 m²/a. Underneath dry crust is a dense and stony till layer adjoining to bedrock.

GROUNDWATER CALCULATIONS DURING THE PLANNING STAGE

Damages caused by the open road cut were valued in the planning stage with pumping tests and

finite element models. Two test wells were constructed during the planning stage, one in the western part of the road cut and the other in the eastern part. Pumping test results showed that tills permeability is weaker in the western part of the road cut. The most permeable layer investigated by test excavations was the washed uppermost part of the till layer. The hydraulic conductivity $k = 1-6 \times 10^{-4}$ m/s in the washed till layer. The thickness of the waterbearing washed layer was about 0.2 m in the western part and 0.5-1.0 m in the eastern part of the road cut.

Wells used in the pumping tests were quite small (diameter 1500 mm) compared to the drainage effect of the open road cut. The influence of this scale difference can be calculated either by traditional well formulas or numerical models. In this case a reasonably exact numerical model could be created because of abundant soil investigation data. The altitude and hydraulic conductivity of the water bearing stratum was placed in the model. The size of the two-dimensional model was 600 m x 1000 m. In the middle part of the model was the road excavation (40 m x 300 m). The boundary conditions were the planned drainage level in the excavation and the original groundwater level on the edges of the model with the exception of the elements adjoining to bedrock. As a result of the calculation were contour lines of groundwater lowering (figure 1) and the amount of groundwater flowing to the road cut. The amount of water discharging to the excavation was estimated to be about 300 l/min.

Settlements of the ground surface on the plan area of single houses and settlements of the crossing railroad bank were calculated with help of groundwater lowering predictions. Settlements of the railroad bank due to groundwater lowering were estimated so large that the old embankment was decided to strengthen with piles.

If the amount of pumped water exceeds 250 m³/day and groundwater lowering causes damages to environment, groundwater lowering in Finland demands a permit from Water-rights Court. A permit to start the project was admitted by Water-rights Court of Western Finland in October 1986 based on economical facts.

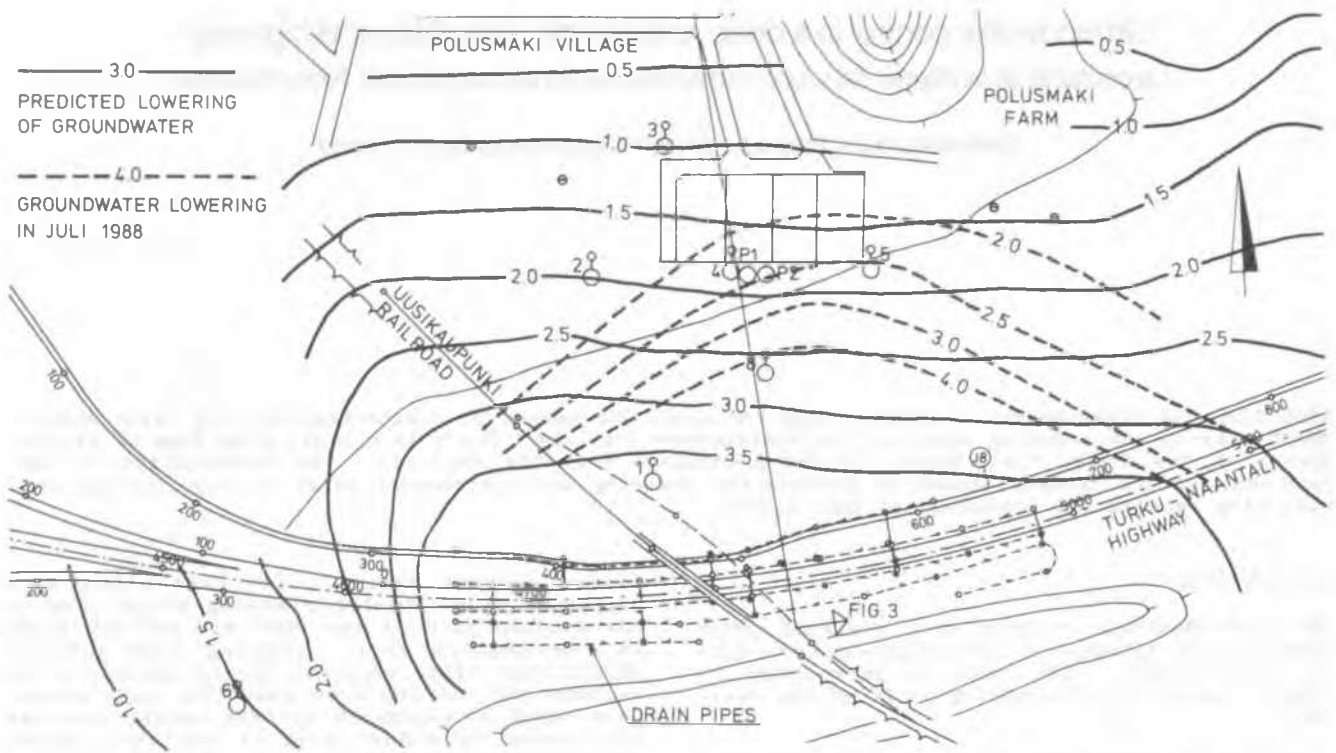


Fig. 1 Contour lines of groundwater lowering

SLOPE STABILITY AND LINING OF THE ROAD CUT

The clayey slopes height in the road cut varied from one to six meters.

Construction of the road cut would be almost impossible without strengthening of the slope because the excavated clay is so soft and sensitive. The slopes were stabilized with supporting embankments made of blast rock. Transferring areas in both ends of rock embankment were strengthened with lime columns. In the transferring areas bottom of the road cut rises from till layers to surface through clay layer.

Groundwater flowing to excavation from the till layers and blast rock slopes must be collected effectively to drainpipes to keep the road construction dry and prevent icing problems in winter. That is why a 1.6 m thick slope lining was planned to the draining part of the road cut. Lower part of the lining consists of a 400 mm thick coarse gravel layer and upper part of till excavated from the road cut.

GROUNDWATER CONTROL UNDER CONSTRUCTION PERIOD

Groundwater flowing to the road cut was pumped directly from the bottom of the excavation. All pumped waters were run through a triangular measure dam to collect data of the groundwater discharge. In the end of the construction period when drainage system was ready groundwater was pumped through the pumping station of the road cut.

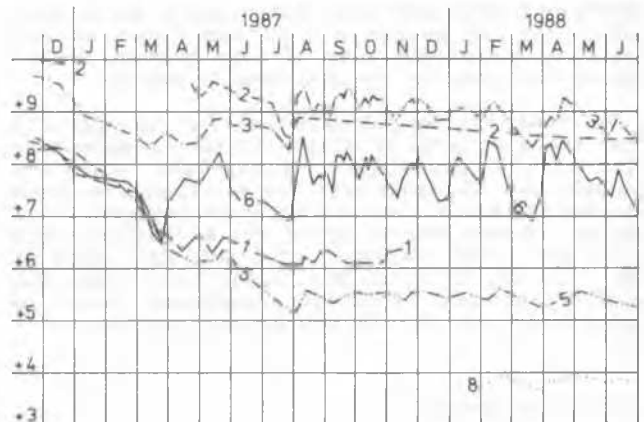


Fig. 2 Groundwater level observations

Groundwater level observation has been done from 7 groundwater observation tubes and 8 wells in the Polusmäki village. Observation results are shown in figure 2. Excavation works started in March 1987. Groundwater table lowered rapidly in the beginning. A cold and dry winter and spring contributed to this. Groundwater table sways due to precipitation. Changes are largest on the edges of the basin. There is no seasonal change close to excavation (less than 150 m distance).

On the basis of observation results groundwater has lowered nearby excavation 5-6 m. In front of Polusmäki plan area of single houses

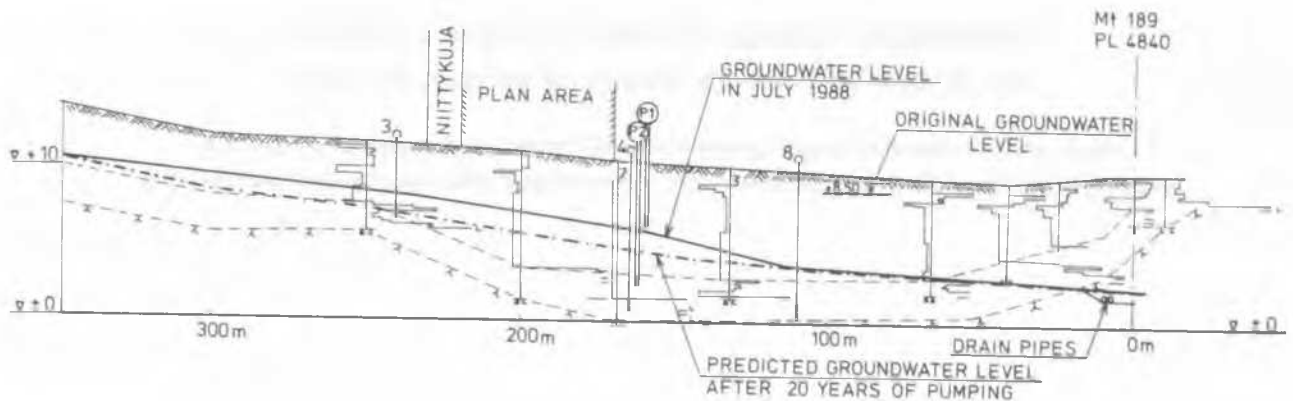


Fig. 3 A cross-section of the clayey field north of the road cut

groundwater level has dropped in 1.5 years about 2.5 m. On Polusmäki farm some 150 m distance from the road cut water has lowered also 2.5 m in the farm's drinking water well and the farm had to be connected to the communal water supply.

PREDICTIONS OF DAMAGE DUE TO GROUNDWATER LOWERING

Hydraulic conductivity of waterbearing stratum has been calculated with a time dependent aquifer model based on finite element method by fitting the calculated results to the observed groundwater curve. New groundwater level predictions have been calculated with the same computer program for a cross-section from the excavation to the housing area. Groundwater level in July 1988 and predicted groundwater level 20 years from the start of pumping are shown in figure 3.

It can be noticed that in July 1988 the groundwater level was already in a stable state up to 100 m distance from the excavation. In front of the area of single houses (160 m distance from excavation) the groundwater level will sink about 1.5 m more in 20 years time. The total drop of the groundwater level will be about 4 m in 20 years. This will cause on the ground surface about 90 cm total subsidence. About 40 % of this will happen during the first 20 years.

The load caused to clay layers due to groundwater lowering has been observed in front of the plan area with two pore pressure probes. Pore pressure measurements showed about 15 kN/m² excess pore pressure in the middle of clay layer 1.5 years after the start of pumping. This causes about 60 cm total subsidence in the surface.

The buildings of the Polusmäki plan area are founded on piles. Street and yard areas will settle and need constant repairing.

CONCLUSIONS

Groundwater level has dropped under construction period slightly more than the original predicted values and groundwater discharge to the drain-pipes has been only 100-150 l/min. This is due to small compensation of groundwater in a relatively small groundwater basin. Because of the small area damages will be limited to the subsidence of streets and yards on the plan area of ten single houses and to drying of some wells in Polusmäki village. In this case solution of open road cut seems to be great saving compared to a watertight concrete trough.