New and Successful Water Sealing Method

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PHOTO: EDVARD IVERSEN

The 1260 m long Storhaug road tunnel has been excavated to improve the environment of the old part of the city of Stavanger. Part of the tunnel is situated below buildings founded on bog, where the rock overburden is between 4.0 and 6.0 m. As the drainage of the bog could cause severe settlement injuries to the old buildings, a maximum leakage of 0.03 l / min / m tunnel was allowed for the most vulnerable 150 m part of the tunnel.

To accomplish this aim, strict requirements formulated by the Norwegian Road Research Laboratory (NRRL) had to be put into operation. Thanks to a successful cooperation between NRRL and the client, the Rogaland County Road Administration, continuous control of the grouting procedure was made possible during tunneling. The tunnel was excavated according to the T12 profile, which means a cross section of 85m^2.

Rock characteristics

The project area is situated in rock that consists of different species of phyllites, ranging from greenish to black coloured ones. The greenish type is richer in chlorite and quartz. The bedrock has been severely subjected to the Caledonian orogeny, and lies situated in a thrust zone between the up-thrusted plates and the Precambrian base rocks. The declination of the rock structure is an average of 70^o to NW and the gullies in the bedrock surface lie along the direction of the strike. The cleavage of the phyllite is very good, except where the folding of the thin layers is intense.

Numerous 1–2 cm thick clay seams are interbedded in the formation, and in the less competent rock they occur with a distance less than 1 m, against an average of 4 m in the area. The clay seems to have a free swelling capacity of 180 per cent, classifying it as of middle activity. The rock is categorized as of soft to medium strength with an E-modul of 0.3–0.5 x 10^4 MPa and an uniaxial strength of 20–80 MPa. The specific gravity lies in the average of 27 KN/m^3. Classification by the RQD (Rock Quality Designation) system is found to be between 25–50.

The ground water level

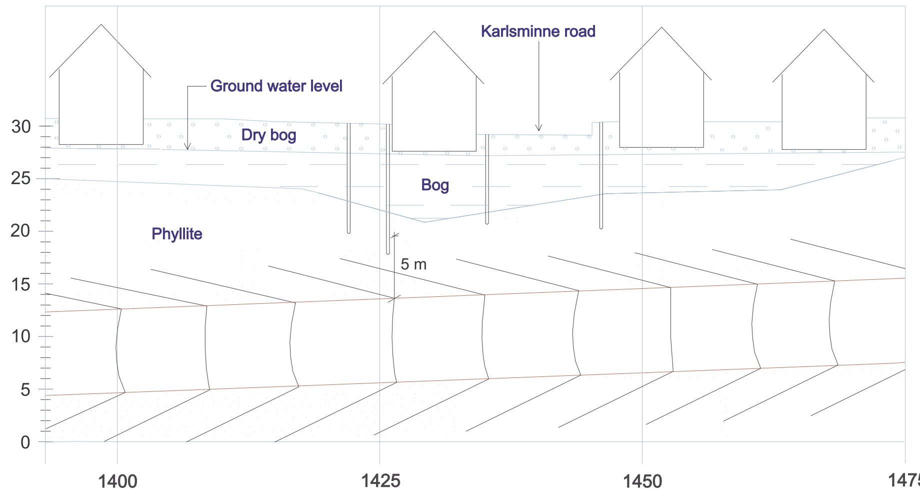
Generally, rocks with interbedded clay seams have low conductivity of water. However, experience has demonstrated that there is conductivity along near vertical crossing lines between certain fissure and fault zones. In addition, along the cleavage layers, there also occur leakages that have to be sealed to fulfil the strict requirements. The initial leakage measured in the drill holes was normally found to be 2–7 l/min, the peak value was 20 l/min.

The ground water level was surveyed in drilled wells during a period of three years before the start of the excavation. It was presumed that maximum natural difference would amount to 1 m, but the measurements have shown that the ground water level varied up to 70 cm. The buildings were surveyed by using photographs, and fixed marks were installed before the start of the excavations. The ground water was monitored by means of 14 piezometers and 19 drilled wells. Six holes with lengths of 25 to 45 m and diameter 115 mm for water infiltration, provided the pregrouting appeared to be unsuccessful, were also drilled. The installations were tested before the start of the excavation. Tests demonstrated that there was insignificant correlation between water pressure tests and leakages in the wells.

Environmental effects

The rock types are classified as having a very poor ability for injection, and should require very high grout pressure to be injected. Because of the low overburden, strict procedures for monitoring and performance of the injection therefore had to be used. To test the drilling pattern and the injection procedure, field tests had to be performed. Also a procedure for controlling the drilling deviation had to be introduced. The leakage is tested by water pressure tests. In the Storhaug tunnel, 14 m long injection holes with an inclination of 18° to the tunnel axis and an overlap of 8 m were found to be the best solution.

Recent injection failures (Hallandsåsen, Sweden, and Romeriksporten, Norway) have focused on the environmental effects of the chemical grouts. Therefore, only cement based grouts were prescribed for the job. To allow for maximum conductivity, microcement – supplied with additives – had to be used.



Longitudal section of the most critical area of the Storhaug tunnel. Even with only a 5 metre overburden, the leakage into the tunnel is only 0.01 l/min/m in this area.

A successful procedure

Tunnel progress was achieved by blasting of pilot and then full profile in 3 m long rounds. The rock was stabilized by 2 m long CT-bolts and fibre reinforced shotcrete. Continuous mapping of the geology was made immediately after the blast and immediately before shotcreting. The initial drilling pattern appeared to be insufficient, and the pattern ended up with 62 drillholes per injection round. After setting, the sealing was tested by drilling and testing of 6–8 holes.

The construction procedure was important in providing a lot of information on tunnel sealing by injection, and useful for water sealing of tunnels in general, especially with regards to the procedures, consequences and costs involved. The leakage measured after the construction was finished was 0.01 l/min/m, a great improvement from the maximum leakage established before the construction started. The consequences for the environment were recorded by the wells and the pore pressure monitoring during the injection, and after. Only three times the grout proceded to the surface. However, the monitoring provided for immediate changes, so no harm was done. The procedure used in the Storhaug tunnel allowed for doing the job according to the strict specifications.