Iceland - Sealing water in Ólafsjördur and Siglufhördur road tunnel excavation

Petr Kučera, Minova Czech Republic Director, and David Cyroň, Metrostav, on the problems of chemical grouting used for water sealing the rock mass in the Ólafsjördur and Siglufjördur road tunnel excavation as published in Tunel magazine.

Introduction

Metrostav was awarded the international contract for the implementation of the Hédinsfjördur project in Iceland, which comprises two road tunnels between the towns of Ólafsjördur and Siglufjördur, in 2006. The two tunnels to be driven were 3650m and 6925m long.

The construction of both tunnels itself started in September 2006 by the excavation of the tunnel from Siglufjördur. The excavation from Ólafsjördur started in November 2006.

The excavation of both tunnels takes place at the Tröllaskagi mountain range (Trolls' peninsula), which is formed by a complex of basic to intermediary rock types with sedimentary interbeds. The rocks are sub-horizontally bedded, disturbed by north-south trending tectonic faulting. The overburden height varies from about 5m in the vicinity of portals to over 800m under Hölsfjall Mountain.

The tunnel design was carried out according to the requirements of Norwegian regulations, where the cross sectional area of a double-lane tunnel is 52.83 square meters. The tunnel is being driven using the drill and blast technique, with the excavation support consisting of anchors and sprayed concrete.

The paper Construction of Road Tunnels in Iceland by the authors Cyroň and Stehlík, which was published in an earlier issue of Tunel magazine, contained detailed information on the progress of the excavation of the above-mentioned tunnels since that time. In the end of the paragraph dealing with the Ólafsjördur tunnel there is the information that water inflows to the tunnel started to increase from the chainage km 13.100, reaching over 2000 l/min. Subsequently, in the final phase, resulted in the suspension of the tunnel excavation.

This article picks up the threads of this information. It is focused on the application of chemical grouting in these tunnels.

Grouting problems

The contract for the construction of the tunnels contained, among other items of work, even grouting operations. It assumed that the pregrouting technique would be used, which is a well known and proven grouting method capable of sealing of leaks of ground water during tunnel excavation in Scandinavia by means of chemical or cementitious materials.

The project owner together with the contractor assess the encountered inflows and jointly decide whether the grouting is to be started when ground water inflows are encountered. The reference limit for the commencement of the grouting is based on the rate of inflows from exploration boreholes, the water temperature and average rate of the flow through the tunnel per each kilometre of its length.

Unless ordered otherwise by the owner's supervision, it applies that if the water inflow from two or more exploration boreholes which are used for the exploration of the tunnel front zone and the finding of contingent ground water inflows exceeds 10 l/s, the contractor jointly with the owner's supervision will start the preparation for drilling and subsequent pre-grouting. When the particular grouting operation is finished, two or more exploration boreholes are drilled to verify the success of the grouting. These boreholes are shorter by 1 m than the boreholes carried out for the grouting purposes.

In the cases of the inflow rates lower than 10 l/s, a post-grouting method is planned in compliance with the grouting specifications that will not disturb the continuity of the tunnel excavation.

Ólafsjördur Tunnel

The excavation of this tunnel is currently passing through Tertiary volcanic rocks comprising above all basalts and, partly, volcanoclastic rocks. The basalts are fine grained to medium grained, both compact and gas-charged, with a frequent occurrence of zeolites. The volcanoclastic sediments are represented by the so-called scoria (volcanic slag) and red sandstone. Sub-horizontal interbeds of fine grained tuffites occur in the basalts. The rock classes (according to CSN 73 1001) vary from R2 to R4.

The trends of the main joint systems are mostly approximately perpendicular to the tunnel axis or are parallel with it. The dip of the joints is very steep, mostly about 80°. Roughly up to chainage km 13.100 the inflows into the tunnel were not significant and did not affect the advance rate of the excavation. From this chainage, the inflow rates started to grow, reaching over 2000 l/min. At chainage km 12.940, the inflow rates further grew, with the pressure reaching about 10 – 15 bar and the water temperature of 2°- 3° C.

For these reasons the decision was made to commence the grouting in the front zone. When the attempt to use cementitious grout for the sealing of the inflows to the tunnel and restart the excavation failed, the site management decided, with the owner supervisor's consent, that Minova chemical polyurethane resins be used.

Because the tender conditions strictly prohibited the use of substances which may harmfully affect the environment or the persons who work with them, Minova had to prove that its products are certified for the contact with potable water and living environment according to North European standards. With respect to the fact that these materials had been successfully

used before on other construction sites in Iceland (the Kárahnjúkar water scheme), all grouting materials submitted to the owner's supervisor were approved.

Apart from the necessary accessories, the chemical grouting set consisted of GX - 45 piston grouting pumps, B3VS - 40 packers and Minova Carbopur WF two-component resin, including Minova CarboAdd Thix 1 and 2 accelerators.

The sealing with polyurethane materials was carried out using the pre-grouting method, following the rules and recommendations designed by Tomasz Najder, a consulting engineer in the field of grouting from Najder Engineering, Stockholm. This specialist was recommended to Metrosta by the owner's supervisor with respect to his long lasting experience of this work in Iceland.

16 - 18 boreholes were drilled ahead of the face, around its circumference. The 12 - 20m long boreholes were subsequently used for the injection of Minova Carbopur WF polyurethane resin into the rock mass.

The objective and purpose of the above described grouting is to create a protective envelope around the entire circumference of the cross section of the mined tunnel by means of the turning of the surrounding rock mass into an impervious material and, to a certain extent, increasing its strength. At the same time, selected employees of Metrostav were, after previous theoretical preparation, practically trained during those grouting operations by specialists of Minova company to be able to use this technique entirely independently as a part of the tunnel excavation procedure, if necessary.

All training was performed within the framework of technical assistance provided by Minova Czech Republic with the assistance of other foreign employees of Minova. The drill pattern and grouting procedures had always to be adjusted to comply with the particular volume of discharge, the geology at the particular chainage and technical conditions for the application of the chemical grouting.

Intercepting traps were installed in the tunnel and at the portal as a part of environmental protection measures with the aim of intercepting, if necessary, leaks during the grouting. In addition, it was necessary in the tunnel excavation sections treated by the grouting to reduce the round lengths during the drill and blast operations. The reason for the use of shorter round lengths was the reduction in the consumption of explosives.

Apart from other aspects, owing to the shorter round lengths, the conditions for the drilling of the grouting boreholes were more favourable and the rock mass at the excavation face was not disturbed so much by the blasting, which was performed in the rock mass which had been significantly fractured even before the blasting.

The grouting was used under the above-mentioned conditions in an about 80 metres long section for about 1.5 months, from the end of May to the beginning of July 2007. The completed "sealing" grouting subsequently rendered the resumption of the excavation in these complicated hydrogeological conditions.

The grouting operations using the polyurethane materials were resumed at the end of August 2007 at chainage km 12.060, but, with respect to the fact that the values of the ground water flow rates and pressures again increased compared with the previous cases, a decision based

on a recommendation Ing. Najder and Minova representatives was made that a higher-performance SK-90 gear-type pump would be applied. The ground water pressure in the pre-boreholes reached up to 30 - 35 bar. The grouting accessories had to also be adjusted to those conditions. The selection of well proven chemical grouting materials was expanded by the adding of Minova Geofoam foam producing resin, mainly because of the fact that cracks and caverns up to O.5m wide were identified the rock mass in the front zone by the pre-boreholes.

Another task was to provide an adequate amount of compressed air for the driving of the SK-90 pump by purchasing a higher-performance compressor and a sufficient stock of the grouting material, with respect to the fact that the consumption increased several times compared with the preceding applications of the grouting. The technological procedure was also adjusted by adding boreholes to be used for the grouting in the front zone by Minova Geofoam with the aim of the filling of the identified free spaces with this more reactive and more foam producing resin.

Common attributes of the application of the chemical grouting in the Ólafsjördur tunnel were, among others, the necessary pre-heating of the grouting materials to 25 - 30°C, including the creation of a moderately heated, thermally insulated space for the grouting pump and material stocks at the excavation face, as well as other accompanying measures associated with the grouting operations, including the occupational safety during this work. All substantial data on the grouting was recorded.

Siglufjördur Tunnel

In this case, the prevailing rock is basalt with apparent sub-horizontal bedding, variable porosity, with transitions to finer grained and more compact facies. The variability of the rock mass properties in the horizontal direction is a result of the conditions under which the thrust sheet originated, therefore, even transitions to smudges of volcanic earthy breccia.

An about 1 m thick layer of sedimentary tuffite was identified during the excavation within a length of 400m. The northeast trending tectonics prevails.

The several 1 - 5m thick shear zones which were encountered consist of mylonitised rock. They are attended by increased inflows of water and have a negative impact on the excavation. The application of chemical grouting with polyurethane materials was necessary only in the cases where the sealing effect of cementitious grout was not guaranteed or the high-pressure ground water was detected in the close vicinity of the excavated cross section of the tunnel.

The risk of uncontrolled inrush of ground water was raised even by the fact that the tunnel was driven on a down gradient from a certain chainage. The grouting procedure using cementitious and polyurethane materials was again based on a method description prepared by a consultant specialised in grouting. The advantage allowing the use of higher proportion of cementitious grout was undoubtedly the fact that the ground water temperature varied between 18 - 20°C and the pressure did not exceed 20 bar. When the chemical grouting using the PUR materials was necessary, GSF - 35 and GX - 45 pumps were applied.

Again, Minova Carbopur WF polyurethane resins were used. The drilling and grouting procedures were similar to those which had been used in the Ólafsfjördur tunnel, with a single exception: the grouting materials did not have to be pre-heated. In some cases it was even the

opposite, which means that the temperature had to be artificially reduced with the aim of the extension of the time of response of the resins being used.

Conclusion

This paper summarises the know-how gathered during the application of chemical grouting in 2007, during the time when the excavation of the two tunnels was not finished. Now, the Siglufjördur tunnel (pictured) has successfully broken through.

The geological and hydrological conditions encountered during the tunnel excavation are among the most difficult in Iceland. Metrostav employees coped with the difficulties of the grouting procedures very well. Their work was appreciated by the supervision and fully complied with the expectations of the owner. However, we must also commend the technical assistance provided during the grouting by the Minova employees. All of the technicians and workers who have participated in the construction have proved that they are able to adapt to very unfavourable unexpected geological conditions.

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“The geological and hydrological conditions encountered during the tunnel excavation are among the most difficult in Iceland.”

Petr Kučera

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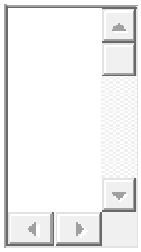

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