Héðinsfjarðargöng Road Tunnels, Iceland

E. Stehlik¹, V. Soukup²
¹Metrostav a.s, Prague, Czech Republic; ²Metrostav a.s, Prague, Czech Republic

1. Introduction

Metrostav a.s. Prague, the construction company from the Czech Republic in JV with local company Háfell ehf started works in North of Iceland in September 2006 and the tunnel excavation works were completed by breakthrough of 3.65 km long Siglufjörður Tunnel in March 2008 and the excavation of the Ólafsfjörður Tunnel, 6.9 km long, was completed by breakthrough on 9.4.2009. During the tunnel excavation works, especially in the Ólafsfjörður Tunnel, the Contractor has met extremely challenging conditions for considerable length of the tunnel. The probeholes drilled ahead of the working face, as a part of the excavation cycle, often found heavy water inflows. Water was under high pressure, maximum measured pressure was 32 bars, adding to the problems was low temperature, which was between 2° - 3°C most of the time. To deal with such extreme conditions, chemical grouting using polyurethane mixes (PU) had to be used.

2. Project Background

To connect two small towns Siglufjörður and Ólafsfjörður in the north of Iceland and to improve Siglufjörður connection with the fourth largest town in Iceland Akureyri, the Héðinsfjarðargöng Project with Siglufjörður and Ólafsfjörður Tunnels (see Fig. 1) was implemented by the government after years of preparation.
After the Project completion, the travelling time between the towns Siglufjörður and Ólafsfjörður will be significantly shortened. This will be important mainly during the winter period, when during the adverse weather conditions, the shortest, 60 km connection between the two towns is often closed; the longer route is 240 km.

In 2006 the Metrostav, in joint venture with the local company Háfell, won the competition to build this project. Metrostav Prague is responsible for tunnelling part; Háfell is responsible for open cut tunnels, bridge, road works and E&M installation. The project is completely financed by the government and the Client is the government organization Vegagerðin (Icelandic Road Administration), supervision performs the Icelandic firm Geotek.

3. Project Description

Project starts from the town Siglufjörður by connection to the existing road and continues on the 2.6 km rockfill embankments towards the first 130 m long open cut section, followed by the mined Siglufjörður Tunnel section with uphill gradient 1% for 1.6 km. The remaining part of the tunnel, approximately 2 km long, was driven with downhill gradient 3%. In the Hédinsfjardar valley (of the fjord Hédins) the route is again in the 110 m long open cut section. In the following section the route goes again on rockfills and bridge (length 14 m) over the Hédinsfjordur River and continues into the 140 m long open cut section. Mined section of Ólafsfjörður Tunnel with uphill gradient 3% is 1.9 km long. After this uphill section the gradient falls to 1% for the length of 5 km towards the last open cut section, with the length of 65 m. The project route is connected at the station km 14.300 to the existing road in town Ólafsfjörður (see Fig. 2).

Mined sections consist of two lane tunnels, the tunnel clearance profile is similar to the Norwegian profile T 8.5. and is 53 m², cross section at emergency bays is 75 m². In regular intervals (approximately 500 m) there are in total 19 emergency bays, three of them with large turning bays (see Fig. 3).

Part of the permanent lining has been installed already during the tunnel excavation and consists of necessary support by bolts and shotcrete required for the safe construction. For permanent bolting the regular re-bar bolts and CT bolts 3, 4 and 5 m long, both types with Combi Coat® have been used; the surface protection is by galvanized coating and epoxy resin. The bolts are supplied by Orsta, Norway. The shotcrete thickness is generally designed to be 50-80 mm, steel fibres are applied depending on geological conditions. The additive TCC 735 for internal curing is applied, except for the first few months of construction, when spraying by water was used. After the tunnel excavation completion, based on an evaluation of the existing geological and groundwater conditions, the support of the tunnel is completed.
by additional layer of shotcrete for the whole profile and permanent bolting mainly in the walls. In areas with water leakage the tunnel will be provided by waterproofing and frost protection system consisting of PE foam sheets anchored to the tunnel lining and protected by shotcrete. Tunnel facilities consist of electrical installations and equipment for lightning, safety and ventilation.

![Regular Tunnel Cross Section](image)

**Fig. 3 - Regular Tunnel Cross Section**

4. Geology

The tunnels are built in the Tröllaskagi peninsula, consisting of the complex of basalt formations with sedimentary interbeds. This volcanic complex is of a lower tertiary age, when short periodical lava eruptions alternated with short periods of volcano clastics sedimentation. The rocks are in sub-horizontal layers and disturbed by dominating NS tectonics. The overburden height varies between 1-5 m at portal areas to 800 m under the highest peak. Some rock spalling occurred where rock overburden was more than 500 m. This layered basalt lava succession with thin scoria and sedimentary interbeds results in mixed face conditions for a large part of the tunnel route.

5. Siglufjördur Tunnel Excavation

Excavation of the 3.6 km long tunnel started in September 2006 and the tunnel breakthrough was on 21.3.2008 (see photo), this resulting in average progress rate of 200 m per month, including two 14 day breaks during Christmas and New Year periods. The best month progress rate was 302 m. The tunnel excavation has been in relatively good geological conditions and without any extreme water inflows. In sharp contrast to the Ólafsfjördur Tunnel the water temperature was mostly between 10-20°C. At the start of the excavation the tunnel was passing geothermal area, which supplies the hot water for the Siglufjördur town; the tunnel excavation has not caused any problems. The biggest problem was 2 km long downhill drive towards Hédinsfjordur, in which most of the intercepted water inflows has been tackled. System of provisional sumps with automatic pumps was installed and worked successfully to remove the water from the face. The water inflows were tackled by cement pre-grouting, totally 460 tons of cement was used for grout. In some cases when the water, despite the regular probe-holes application, was close to the face, the polyurethan (PU) pre-grouting had to be used; in total 40 tons of PU was spent.
6. Works in Hédinsfjördur

Before the Siglu Tunnel breakthrough to this beautiful and not accessible fjord, which was lived-in until fifties of the last century, some preparatory works were done, consisting mainly of soft deposits and loose rock removal from the portal areas and construction of temporary road across the valley, connecting both portals. Limited and light machinery for these works was transported by sea. After the Siglu Tunnel breakthrough the heavy machinery gained the access and after temporary bridge construction the final works on open cuts for the both portals proceeded.

7. Ólafsfjördur Tunnel Excavation

Excavation of the 6.9 km long tunnel started in November 2006 from the Ólafsfjördur site, and total of 5 km of the uphill tunnel excavation was completed from this site. For the first 1 km the water inflows into the tunnel were not significant, with low impact on the excavation itself, later the water ingress started to be higher and for following 3 km the water was causing problems. The average rate was slightly under 180 m per month on this drive.
Rate was affected by delays caused by unexpected hydrological conditions and need to use extensive pre-grouting to reduce the water inflows from the probeholes to specified limits; in total nearly 600 tons of chemical grout was used for this part of the tunnel. The best monthly progress rate was 330 m. Geothermal zones close to the tunnel alignment at the start of the excavation were not affected. Because the hot water supplying Ólafsfjördur from these zones is coming under the natural pressure, there was a fear that experienced heavy inflows into the tunnel during the excavation might affect this natural pressure, fortunately this was not the case. The water temperature in this part of the tunnel was between 2°C- 4°C, except for the last few hundred meters, before meeting the counter drive, when the temperatures rose to 9°C.
The uphill drive of the Ólafsfjördur Tunnel from the Hédinsfjördur site started early May 2008 and the 1.9 km long uphill section was completed in January 2009, giving average progress of 210 m per month. Geological and hydrological conditions were relatively good, without need for pre-grouting.

8. Methods and Equipment

The part of the excavation process has been a systematic drilling of generally 1 to 2 probeholes with 51 mm diameter, which were drilled in lengths 25 m to 32 m, with 6 m overlap. The probeholes drilled by Axera Tamrock T11-315TCAD drill rig served for the verification of the geological conditions and mainly for detection of the ground water presence. Based on volume of the water and its pressure and temperature, the decision about further advance was jointly taken by the Contractor and Supervision.
The face drilling was by the same three boom drill rig Tamrock as for the probehole drilling, the hole diameter was 48 mm. In both tunnels the round were usually drilled to the full length 5.27 m with resulting pullout between 4.7 to 5.0 m. In the case of difficult geological conditions the round length were shortened to 3.0 m. The drill rigs have semi-automatic system TCAD, which is the program to measure the position and the direction of a drilling bit. By help of a laser beam, the drilling pattern and boom positions are correlated with the tunnel alignment coordinates. The operator afterwards secures the exact drilling of the pattern by hand positioning of the boom. There were two mentioned Tamrock drilling rigs on the site (photo with water), which drilled in total 40 km of holes for pre-grouting and 32 km of probeholes (both with 51 mm diameter); the total length of blasting holes with 48 mm diameter reached nearly 1 500 km. The drill rig performance was very reliable and proved to be good choice for the conditions, although in many cases the contractor wished that the rigs have “submarine” features, due to the heavy water inflows.
muck loading was by loader Broyt D600W with the 3.4 m³ shovel. The equipment is without its own drive and to transport it to the tunnel face the dumper had to be used. The movement at the face is by bracing the equipment by shovel, followed by turning it into required position. The start of working with this loader was connected with some problems, mainly in respect with the timely operator training and also with the breakdown rate. However, the loader performance is, comparing to the wheel loaders, unmatched. Moreover, it was used for invert excavation and also for the first scaling operation. As a back-up the Volvo 180E wheel loaders were available on the site.
The mucking was provided by the Komatsu dumpers, mostly with 35 tons capacity (see Fig.4). Their number in one tunnel was 6 as a maximum. The muck was dumped both into the temporary and permanent dumping sites located close to the tunnel portals. Suitable material has been further treated in a crusher into different fractions and used for rock fills for the future road works.

![Fig. 4 - Broyt loading Komatsu truck](image)

Generally, the blasting emulsion Titan 7000 (now called Civex), supplied by the "Orica Mining Services" (formerly Dyno Nobel) through the local company Ólafur Gíslason & Co, was used. Charging was by the pumping unit Mini SSE (Site Sensitized Emulsion), which was transported to the tunnel face by a small truck. With this system the emulsion could be pumped into two holes simultaneously. The system allows changing the charge according to the type of the blast hole. It was confirmed that the emulsion is suitable for blasting in hard and brittle rocks. In softer rocks, with "plastic" properties is the use of emulsion more problematic. In the case of porous tuff it was was better to use classical explosives (supplied also by Orica). In some cases the combination of both types of explosives was used. As a boosters the 25 g Nobel Prime® boosters were used, which were inserted into the blast holes together with non-electric detonators NONEL LP during the emulsion pumping.

The ventilation system was designed as separate blowing ventilation. The tunnel ventilation in Ólafsfjördur Tunnel was provided by 1 x 1800 mm and 1 x 2100 mm diameter non-reinforced ducts and two axial ventilators Cogemacoustic, type T2 180. Ventilators have frequency converter allowing smooth revolution regulation according to the length of excavated tunnel.

The shotcrete application is by the Meyco Potenza pump and robot arm, the wet shotcrete method uses concrete C 35/40. Accelerator Meyco SA 162 produced by BASF and later SIKA Sigunit L53 have been used. Based on the encountered geological conditions the steel fibres SIKA Fiber CHO 65/35 NB are applied to the shotcrete mix. Before the shotcrete application the excavation has to be carefully cleaned to remove the dust and small rock pieces. Cleaning is also done by the Meyco Potenza equipment, which fulfills the specified requirements in respect of a volume and pressure of the cleaning air/water jet. Concrete is supplied and delivered to the site by truck mixers by Icelandic company BM Vallá.

9. Ground Water Challenges, Pre-Grouting

Water was the main challenge of the Project, mainly for the 5 km long uphill excavation of the Ólafsfjördur Tunnel. When the large water inflows of high pressure were indicated by regularly drilled probeholes (see Fig. 5), the pre-grouting procedure was initiated, based on specified volume of water from the probeholes.
These limits were modified by the Supervision based on actual conditions, but usually the limit 600 l/min from two holes was a signal to start the pre-grouting.

Because of low water temperature (2-3°C) the classical cement grouting was not successful and after few unsuccessful attempts, using Unigrout EH 400 from Atlas Copco, the chemical grouting was required. Two component injection resins CarboPur WF and WFA together with additives CarboAdd Thix 2 and CarboAdd Fast and also rapidly reacting and strongly expanding Geo Foam were supplied by Minova CarboTech GmbH. The chemical components were injected by piston pumps GX-45 II, in the case when larger volumes were required to be injected, the gear-type pumps SK-90 were applied. For extreme conditions the electric pump CT-PM was prepared on the site, fortunately was never used. For closing the holes the hydro-pneumatic packers BVS-40K attached to the injection pipe were used in most of the cases and due to the high water pressures they were usually used in pairs. All the mentioned equipment and accessories were also supplied by Minova and their specialists from Germany and the Czech Republic provided technical help during the whole course of works.

The basic description of the pre-grouting procedures has been described in the Tender Documents, but the procedures had to be modified to suit the actual conditions. The Contractor hired T. Najder (Najder Engineering, Sweden), who is a specialist for pre-grouting works.

The usual procedure, after the water was found and pre-grouting was ordered by the Supervision, started with drilling of grouting holes, in many cases creating the complete grouting umbrella, consisting of approximately 20 holes, 12 m to 20 m long. These holes were grouted by pair of pumps, after completion the quality of pre-grouting was checked by additional probeholes, which were subsequently grouted and the procedure was repeated if required. In some complicated cases even 40 holes were drilled from one face, on the other hand in some cases only parts of the umbrella were drilled and grouted.

Because the water pressure in extreme cases reached 32 bars, the installation of packers was difficult, until the contractor manufactured aids allowing the installation of packers into the hole e.g. with 60 l/sec under 30 bars pressure inflow by boom of Tamrock drill rig. Despite all the improvements the working conditions during the 12 hour shifts, in cold water environment, were extreme. Metrostav a.s. workers despite such conditions, mastered the pre-grouting works after short learning curve.

In July 2008 the water inflows were such that it was impossible to stop them by pre-grouting and the tunnel was subsequently flooded. The total volume of water from the tunnel reached nearly 600 l/sec (see Fig. 6).
10. Progress of Other Works

Háfell completed all four open cut tunnel sections by the end of 2009, using custom made travelling formwork, manufactured by Metrostav in Prague. The works were often complicated by extreme winter conditions, with heavy snow and winds. Works on roads inside and outside the tunnels were progressing according to updated construction schedule. Waterproofing and frost protection works started in November 2009.

11. Conclusion

The unexpected heavy inflows of cold water under high pressure encountered during the tunnel excavation delayed the construction of the Project. After negotiation between the Client and the Contractor the extra time and financial compensation was awarded by the Client, and the new date of the Project completion was moved to the end of September 2010.

Generally, the Metrostav effort on the tunnels excavation in the extreme conditions received well-deserved high appreciations from all involved, including the Client, Supervision and local community. It has to be mentioned that the support to the Project and to the Contractor from the local people has been enormous and there are very good relations between the parties.

12. References