ABSTRACT

The development of the Ilulissat hydropower station in Greenland commenced and was completed in 2009 and 2014, respectively. It is located in the west of Greenland, in the Arctic zone, 200km north of the Arctic Circle. The power plant output amounts to 22.5 MW. It supplies the town of Ilulissat, which till the facility commissioning used fossil fuels for power generation, with electric power since 31st October 2012. The power plant uses water from two lakes (Paakitsup and Akuliarussuaq), which originated from melting glaciers. Its distance from Ilulissat is 60 kilometres. The transition of electric energy is secured both by overhead and underground high-voltage lines. The underground power plant, headrace and tailrace tunnels are found in permanently frozen ground. Regarding geology, Pre-Cambrian gneiss dominates in the particular region. The Norweigian Tunnelling Method is applied, using the drill-and-blast technique. The technically most complicated part of the works was the excavation of the powerhouse, which is 23.4m high, 34.8m long and 136m wide. Among the factors which influenced the course of the construction of the underground hydropower station there were demanding climatic conditions and the difficult-to-assess location.

INTRODUCTION

Greenland with its area of 2,175,600km² is the largest island in the world (see Fig. 1). Only 15% of the area, roughly equal to the size of British Islands, are permanently unglaciated. The remaining part is covered with ice. Its thickness locally reaches up to 3000m. This glacier, covering roughly 1.8 million km², is the second largest in the world after the Antarctic glacier. The island is inhabited by a mere 56,000 people; out of this number, there are 48,000 Inuits there. Greenlandic is the official language there.

Obr. 1 Mapa Grónska
Fig. 1 Greenland map
Elektrárňa má inštalovaný výkon 22,5 MW. Elektrickou energiou, ktorú vyrobí pomocou troch 7,5 MW Francisových turbín, zásobuje mesto Ilulissat (obr. 3), kde žije 4500 obyvateľov. Zariadenie nahradilo doterajšie naftove generátory, takže mesto už nezávisí od dodávok pohonných hmôt na výrobu elektriny.


Podzemné objekty tvoria (obr. 2):
- odtokový tunel – 1873 m;
- vstupný servisný tunel – 646 m;
- podzemná strojovňa – 6846 m³;
- hlavný vodný privádzací – 1470 m;
- hlavná vpuť – 593 m;
- prepojovací tunel medzi jazerami 233 a 187 – 1510 m;
- celková dĺžka tunelov – 6093 m.

GEOLÓGICKÁ STAVBA


Greenland uses fossil fuels to cover its own power consumption, amounting to ca 232 million kWh (54% oil and 41% water resources).

The first hydropower scheme was developed in Greenland in 1993, near Buksu fjord, south of the capital, Nuuk. The nominal output of the power plant is 30MW and the power is supplied through high-tension lines across two fjords. The largest span between two electricity pylons of up to 5376m is across Ameralik fjord.

The Ilulissat hydropower plant is the third project realised by Greenland-based power generation company Verkís, after the 7.5MW Qorlortosuaq hydropower scheme (operating since 2006) and the 15MW Sisimiut plant (operating since 2009).

CONSTRUCTION CHARACTERISTICS AND BASIC DATA

The Ilulissat hydropower scheme is located in the west of Greenland, 200 km north of the Arctic Circle; it is situated on the 69th degree of north latitude (see Fig. 2).

The installed capacity of the power plant is 22.5MW. It supplies the town of Ilulissat (see Fig. 3), the population of which reaches 4500, with electric power generated by means of three 7.5MW Francis turbines. The facility has replaced the until then used oil generators, which means that the town no more depends on supplies of fuels required for the power generation.

The hydroelectric generating station is located at the distance of 60 kilometres north-east from Ilulissat, in the Disko Bay – Pakitsoq location (see Fig. 4). It uses water from two lakes, Paquetsup and Akuliarsersua, originating...
from melting glaciers. The underground power plant and the headrace and tailrace tunnels are found in permanently frozen ground. Electric power is transmitted to Illulissat through 50km long underground and overhead high-tension lines.

There are the following underground structures there (see Fig. 2):

- the tailrace tunnel – 1873m;
- the access tunnel – 646m;
- the underground powerhouse – 6846m³;
- the headrace tunnel – 1470m;
- the intake 187 tunnel – 593m;
- the tunnel interconnecting the lakes 233 and 187–1510m;
- the aggregated length of the tunnels – 6093m.

**GEOLICAL STRUCTURE**

Regarding geology, Pre-Cambrian gneiss dominates in the particular region. The rock is relatively coarse-grained, extremely hard and massive. Quartz accumulates in bands up to 0.5m thick and biotite forms small fault surfaces in gneiss. The increased ground pressure caused problems during the tunnel excavation in some parts of the ground massif. Problematic zones were sporadically encountered in the area containing faults.

**TECHNOLOGY, TECHNICAL CONDITIONS AND CONSTRUCTION PERFORMANCE**

The excavation was carried out using the Norwegian Tunnelling Method (NTM) with the application of the drill-and-blast technique. It has a lot of things common with the NATM – the New Austrian Tunnelling Method, but in reality principally differs from it. The difference lies in the assessment of geology (Q-system), in the method of supporting the excavated opening and in the technique of protecting the works against water seepage.

**Equipment for the excavation support:**

- shotcrete reinforced with steel or plastic fibres;
- CT rockbolts, SN 2-4m long.
Thermally insulated, heated, plastic water pipelines 63mm, 75mm and 110mm in diameter were used in all parts of the tunnels.

The excavation itself consisted of the drilling of up to 4m long holes using 48–51mm bits. The drilling using the semi-automatic TML system allowed for precise drilling into the excavation face according to drilling patterns pre-prepared for all mined structures of the project. In this way, undesired overbreaks were minimised. The system even allowed for backchecking on the drilling rig operator. The DAP explosive powder was used for the rock disintegration. It was mixed in the proportion of 3.5 litres of fuel oil to 50kg of ammonium nitrate and subsequently was blown into the blast holes by means of a charging truck. Eurodyn Magnasplit plastic explosive was used in sections with water inflows. NONEL detonators were initiated by means of a detonating fuse at the firing point. The 80g blasting fuse was applied to contour holes. The majority of the tunnel structures were driven through rock excavation classes I and II, where excavation support was carried out only sporadically, in accordance with the design documents, according to which the support was installed systematically only in excavation classes III and IV. Really extraordinary attention was devoted during the course of the excavation to the high quality mechanical and manual scaling of the heading after blasting. As a result of the systematic heating of the permanently frozen rock during the production process, the rock suffered from weathering. Because of safety reasons it was unavoidable to manually clear the critical sections repeatedly, as required. Turning bays (400m²) were carried out every 200m of the tunnel length for the needs of the loading and transport of muck in the tunnel.

**Tailrace tunnel**

It was the first and at the same time the longest tunnel to start to excavate. Its total length and excavated cross-sectional area amounted to 1873m and 17.2m², respectively (see Fig. 5). The excavation was carried out from October 2011 to August 2012. Draft tubes from the underground power plant, 35.5m long each, with the cross-sectional areas varying from 17.2m² to 7.9m², belonged among the workings. The tailrace tunnel was driven in the direction against the flow of water discharging from the power plant; 300m of its length were driven uphill at the gradient of 0.2%. The remaining part was driven downstream on down gradients of 10% and 0.2% along the lengths of 250m and 680m, respectively. The tunnel bottom at its discharge to the sea is located ca 4m under the sea surface. The 60m long access tunnel with the profile of 17.2m² is also located in this part. The so-called „Water mist” system was installed by Atlas Copco on the drill rig. Owing to this system, the consumption of pressurised water for drilling is reduced to 10% in comparison with the common consumption.

**Access tunnel**

It was driven down a 10% grade from September 2010 as the second structure of the project (see Fig. 6). The main part of it is formed by a 419.9m long tunnel with the cross-sectional area of 30m². This tunnel is interconnected by two tunnel tubes with the 68.19m long tailrace tunnel and the 91.5m long headrace tunnel; the cross-sectional area of both tunnels is 19.8m². Another structure of this part is the transformer station with the cross-sectional area of 82.5m² and the...
povolená minimálna tolerancia odchýlenia sa od predpísanejho výškou a lokálné geologické poruchy s nevýhodným smerovaním uloženia horninovej masy. Práce boli rozdelené na dve etapy. V prvej etape sa razila vrchná časť komory v oblúkovom tvare, ukončená v spodnej časti oboch strán nosnou hranou žeriavovej dráhy. V tejto časti bola použitá „Metóda hladkého výlomu“, navítaním obrysových dier s max. odstupom 15–20 cm s použitím 80g bleskovice. Zaistenie vrchnej časti komory bolo realizované striekanou betónovou zmesou s plastickými vláknnami a zabudovaním systematických 4 m dlhých skalných CT kotelov. Na prevziazenie žeriavovej dráhy boli zabudované v uvedenom mieste 6 m dlhé skalné SN kotvy pod presným uhlom. Druhá etapa pozostávala z razenia spodnej časti komory metódou „Prespliting“. Po obvoďi strojovne sa navŕtili vývrtky s odstupom 20 cm a počas odpalu bola táto časť horniny rozpokená v časovom predstihu oproti zvysku rozpojovaných hornín. Celkovo bolo potrebných 77 dní do ukončenia vrtaných-trhacích prác v tejto časti projektu. Na pracovisku boli strojírni, podľa typu práve prevychádzajúcich prác, nasadzovaní 2 až 4 pracovníci.

Hlavný vodný privádač

Dĺžka tunela je 1470 m s profilom 17,2 m². Raziace práce prebiehali v období od marca 2011 do mája 2012. Tunel bol razený dovrchné, v smere proti prúdu vtekajúcej vody do turbín elektrárne, z toho 570 m so sklonom 1,3 %, 500 m so sklonom 7 % a 400 m so sklonom 16 %. Aj v tomto tuneli stú v danom prípade situované prítokové chodby do podzemnej 18.5 m² profile cable tunnel and a connecting tunnel, at the aggregated length of 46.5m. Two service recesses with the profile of 49.7m² and 15.7m², respectively, and at the aggregated length of 20m are parts of the access tunnel. All of the above-mentioned parts were finished in June 2011.

Powerhouse

The powerhouse chamber is 23.5m high, 34.8m long and 13.6m wide. The excavation of the chamber commenced in November 2010 and was a technically quite demanding part of the works (see Fig. 7). There were the following reasons: the minimum tolerance permitted for the deviation from the prescribed excavation contour, the dissected bottom with its variable height and local geological faults with unfavourable trends of the rock bedding. The work was divided into two stages. The curved-shape upper part of the chamber, which was terminated in the lower part of both sides by a load-bearing edge of a crane track, was driven during the first stage. In this part, the Smooth Blasting Method was applied, with contour holes drilled at the maximum spacing of 15–20cm, using an 80g detonating fuse. The support of the upper part of the chamber was provided by shotcrete reinforced with plastic fibres and systematic 4m long CT rock bolts. The crane track was tied with 6m long SN rock bolts installed at a precise angle. The second stage consisted of the excavation of the lower part of the chamber, using the “Pre-splitting technique”. Holes were drilled at 20cm spacing around the powerhouse cavern contour and the rock was disintegrated in advance of the remaining proportion of the rock to be disintegrated. The completion of the drill-and-blast operations required for this part of the project claimed the total of 77 days. Two to four workers, depending on the type of the work just underway, were alternately deployed at the workplace.

Headrace tunnel

The cross-sectional area of the 1470m-long tunnel amounts to 17.2m². The headrace tunnel was driven in the direction against the flow of water flowing to the powerhouse turbines. 570m of its length were driven uphill at the gradient of 1.3 %, 500m on the gradient of 7% and 400m on the gradient of 16%. Even in the case of this tunnel, the gradient of the 50m-long, 17.2m² to 6.7m² cross-sectional area penstocks leading to the underground powerhouse varies. Up to 14m of these
tunnel tubes were driven using a hydro-pneumatic hand-held drill (see Fig. 8). Three rocktraps, which were always carried out across the whole tunnel width, are distributed along the route. Approximately a half of the tunnel was driven concurrently with the independent counter-heading in the area of the powerhouse or the tailrace tunnel, using crews of four and later only three. The last 200m long section was carried out by means of pre-drilled holes and, if necessary, grouting, as in the case of the following tunnel.

**Intake 187 tunnel**

It was the technically most complicated part of the project (see Fig. 9), where the so-called Norwegian Method of breaking through to the lake was applied. The excavation got to the vicinity of the lake surface through the access tunnel with the cross-sectional area of 17.2 m² and the length of 497m, marked as the 187m a.s.l., where the difference in altitudes of the tunnel bottom and the lake surface edge was 55m. At the beginning of driving the tunnel under the water surface, four 24m-long probe holes were bored. Subsequently, eighteen 16m long probe holes were carried out and filled with cement mixture at the prescribed pressure. The tunnel was opened by three excavation rounds with the length reduced to 2.5m each. This process was cyclically repeated. The following steps toward the lake centre followed:

The cavern for the main water valve with the length of 14.8m and the disintegrated rock volume of 880m³ was excavated.

Two interconnecting tunnels were driven at the end of the cavern, perpendicularly to its axis (see Fig. 10). The cross-sectional area of each of them amounts to 17.2m². The right-hand one is 11.7m long, whilst the length of the left-hand one is 8.6m.

A 16.2m deep shaft with the dimensions of 3x3m was excavated at the end of the right-hand interconnecting tunnel. It connected the main water supply – the headrace tunnel – with the intake tunnel.

The last part, the intake cavern with the volume of 6700 m³, was driven from the left-hand interconnecting tunnel. It is 19.2m high, 45.2m long and 14m wide in the lower half of the profile. The roof is arched. It is supported with shotcrete and sporadic 3m long CT rock bolts. The sidewalls are supported in the lower half systematically with similar rock bolts. Holes for the final blasting were drilled around a 6.6m diameter circular contour at the highest point of the cavern. The length of the drillholes made to the hard rock ranged from 1.5m to 7.5m.

Power supplies to the town of Ilulissat commenced on the 31st October 2012, after Norwegian specialists successfully broke through the lake bottom covered with an up to 12m thick layer of sediments on the 30th September.

**CLIMATIC CONDITIONS**

As a neighbour of the North Pole, Greenland has the Arctic climate, despite the fact that there are significant differences from the north to the south and from the coast to the inland. It is in general possible to say that the climate is very dry and, as a result, the felt air temperatures are completely different from the majority of other places in the world. Temperatures ranging from 10–18°C appear to be very hot, whilst -10°C is an equivalent to a pleasant temperature. The lowest temperature during the construction period reached -38°C. The sun
Na konci kaverny sa kolmo na jej os vyrazily dva prepojovacie tunely (obr. 10) v profíle 17,2 m². Pravý má dĺžku 11,7 m a ľavý 8,6 m. Na konci pravého prepojovacieho tunela bola vyrezána šachta do hlbky 16,2 m s rozmermi 3x3 m, ktorá spojila hlavný vodný prívadzác s vypustou.

Z ľavého prepojovacieho tunela bola razená posledná časť, kaverna vzpusté s objemom 6700 m³. Je vysoká 19,2 m, dĺžka 45,2 m a široká 14 m v spodnej polovici kaverny. Strop je obľúkovaný, zaisťený striekanou betónovou zmesou a sporadicky 3 m skalnými CT kotvami. Bočné ostenie je zaisťené v spodnej polovici systematicky podobnými skalnými kotvami. V najvyššom mieste kaverny boli navítané vývrtky s obrysom v tvare kruhu priemeru 6,6 m po finálnym odpal. Dĺžka vývrtov v pevnnej hornine bola od 1,5 m do 7,5 m.


KLIMATICKÉ PODMIENKY


ZÁVER


IGOR HARACH, igor.harach@tucon.sk, TuCon, a. s.


LITERATÚRA / REFERENCES
