DECEMBER 2010

tunnels & tunnelling

HEDINSFJORDUR TUNNEL

- Olafs Tunnel is 7.1km long
- Siglu Tunnel is 3.9km long
- Up to 800m of overburden
- Water ingress pressures up to 32 bar
- Water temperatures as low as 2°C
- 630 tonnes of PU resin grout used
- Work started in 2006
- Tunnel opened 2 October 2010

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Blasting Iceland's frozen north

We explore Metrostav's Hedinsfjordur project

The Blanka complex of tunnels in Prague is the largest underground construction project currently underway in the Czech Republic.

www.metrostav.cz

welcome

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On the cover

Moment of detonation! Workers make progress on the Hedinsfjordur project using drill and blast

Road Tunnels in Iceland

Iceland is building more road tunnels, and they are getting longer. The most recent and longest scheme to date, is Hedinsfjordur Tunnel, which has two single tubes totalling 11km. Built by Metrostav-Hafell JV, the tunnels opened to traffic in October

Above: **Location of the key road tunnels built and in planning in Iceland**

With its complex geology, Iceland presents a range of challenges to tunnellers. The desire for new passages to be blasted through mountain ridges comes from the country's small population seeking improved and safer, transport links over the island's rugged terrain. Long and exposed winding roads snaking up valleys or round the steep edges present difficult and time-consuming journeys, especially during the severe winters and long hours of darkness.

Going underground, therefore, can offer benefits both locally and, on a cumulative basis, nationally – even if the traffic volumes are relatively small in general.

The tunnel solutions for the road network have come as single tubes of generally increasing length over the recent decades since the late 1940s, culminating in the longest scheme so far, Hedinsfjordur Tunnel, which has two tunnels of 11km total length and was opened to traffic in October by the Icelandic Road Administration (ICERA), or Vegagerdin.

Iceland's road tunnels, including the two that form the Hedinsfjordur project – Olafsfjordur and Siglufjordur – are near the coast and have been excavated by drill and blast, including the first subsea crossing, at Hvalfjordur, which is its only toll tunnel, so far. That financing model is being considered for the 11th tunnel scheme on the island, Vadlaheidi, near Akureyri, the main town in the north of the country and not so far from the latest addition, Hedinsfjordur.

Traditional Nordic excavation by drill and blast has dominated the road tunnel market in Iceland and while no role has been played as yet by TBMs – unlike the construction of hydropower tunnels in Iceland, which are also more inland and generally longer – the possibility is there. At least on one prospective large road tunnel project being studied, at Mid-Austurland, in east Iceland, which could see TBMs involved.

An immersed tube is one of the alternatives for the Sundabraut crossing within the capital, Reykjavik, though it is squaring off against a bridge option and a rock tunnel in a tough economic climate.

Road tunnels - built

The 10 tunnel schemes in Iceland range from the shortest, Arnardalshamar, opened in 1948 near Isafjordur in the northwest of the country at barely 30m long, to the longest, Hedinsfjordur. The most recent addition, though by only a week, the Hedinsfjordur scheme consists of two tubes – Olafsfjordur (7,100m long) and Siglufjordur (3,900m).

Most of the bores in the road network, except for two – Oddsskard (640m, opened in 1977) in the east and Straka (800m, 1967), near Siglufjordur, are well over 1km in length and carry two-lanes. Opened in 2005, the Almannaskard tunnel in the

Hedinsfjordur Tunnel	*11,000m*	*Olafsfjordur 7,100m*; *Siglufjordur 3,900m*
Breididalur-Botnsdalur Tunnel	*9,160m*	*Breididalur 4,150m*; *Botnsdalur 2,907m*; *Tungudalur 2,103m*
Faskrudsfjordur Tunnel	*5,900m*	
Hvalfjordur Tunnel	*5,770m*	
Oshlid Tunnel	*5,400m*	
Muli Tunnel	*3,400m*	
Almannaskard Tunnel	*1,300m*	
Straka Tunnel	*800m*	
Oddsskard Tunnel	*640m*	
Arnardalshamar Tunnel	*30m*	

Double lane *Single lane*

Left: **Ranking of built road tunnels in Iceland, the longest being the most recently built – Hedinsfjordur Tunnel Project, which includes the Olafsfjordur and Siglufjordur tunnels**

Right and above: **The newest road tunnel in Iceland – Hedinsfjordur Tunnel – was built by Metrostav-Hafell JV and consists of two single tubes, Olafs and Siglu, together make the scheme the longest in the country**

southeast is the shortest double lane tube at 1,300m long.

However, there are longer single lane tunnels (with regular widened sections for passing points), such as Muli (3,395m, 1991), near Olafsfjordur, and also Breididalur (4,150m, 1996) and Botnsdalur (2,900m, 1996) which form two branches out of three in the near T-junction on a major northwest scheme.

The other three double-lane road main tunnels in Iceland are Faskrudsfjordur (5,900m including 200m of concrete portals, opened in 2005), the Hvalfjordur subsea tunnel (5,770m, 1998) and the Oshlid Tunnel (5,400m), which opened in September 2010.

Oshlid Tunnel was built between Isafjordur and Bolungavik in the northwest of the country by a JV of Marti with local firm Islenskir adalverktakar. Excavation of the tunnel – 5,156m of which was in rock – was subcontracted to Slovakian firm Tubau, and 600m of concrete portal was built by a local firm, Vestfirskir verktakar.

There is also another double-lane tube, which is part of a larger scheme mentioned before and is the third tunnel of the three in the northwest T-junction scheme – Tungudalur (2,100m, 1996).

Road tunnels - Planned

Iceland has had a number of potential road tunnel projects under study for years and is gradually completing them in order, and while the weakened national economy presents a challenge for financing at present and the near future, the country has strategic plans to develop further schemes.

Despite the funding challenges to foreign travel, for the time being, this strategy needs the Icelandic tunnellers to stay active and linked with the peers internationally, to discuss the experiences and lessons of tunnelling with mainly basalts, tectonically active areas, groundwater problems and rapidly changing sequences of strata.

Hreinn Haraldsson, director general of Vegagerdin and also the current president of the Icelandic Tunnelling Society, says: 'We not only want to, but we must continue to be involved in the international community because we will construct a lot of tunnels in future.'

Key road tunnel projects in preparation or in studies, for development in the near future, in Iceland, include: Vadlaheidi, Nordfjordur, Arnarfjordur-Dyrafjordur, Sundabraut, Mid-Austurland, and another tunnel under Hvalfjordur.

In the longer-term, Vegagerdin is examining road tunnel projects at Lonsheidi and Vopnafjordur-Herad.

Vadlaheidi Tunnel

Vadlaheidi road tunnel is planned to be built through the mountain ridge forming the east side of the fjord at Akureyri, the main town of north Iceland. The tunnel is designed as a single tube approximately 7,800m long. The tunnel is to be 9.5m wide and maximum clearance for vehicles is a standard 4.6m for Iceland.

The scheme was envisaged in 2007 on a BOT model and then the planning anticipated tendering possibly in 2008. However, the project has yet to go ahead due to the tightened financial climate, of the last couple of years.

Talks are now underway with pension funds about loans to fund the project. As the state can't take the loan, Parliament has decided to establish a special purpose company, 51 per cent held by Vegagerdin and the balance by local interests, to undertake the project. Once the pension funds involvement is determined then it will become clear if an open call for international funding will also be made.

If funding agreement is reached with the pension funds before the end of the year then Vegagerdin would expect a pre-qualification call to contractors in early 2011 and tendering shortly after for award around mid-year and work starting by the third quarter. The project is expected to take three years to complete.

Vadlaheidi is projected to attract 1200 vehicles per day, and traffic is estimated to

Right: **Hreinn Haraldsson, director general of Icelandic Road Administration, Vegagerdin, and president of the Icelandic Tunnelling Society**

Above: **Hedinsfjordur Tunnel was opened on 2 October 2010, and links communities separated by long, often impassable roads in winter on the coast of north Iceland**
Photo Credit: Stepan Soukup

increase 8 per cent in first year of operation and 3-4 per cent annually afterwards, in the short-term.

Nordfjordur Tunnel
In the east of Iceland, a single tube road tunnel is being studied in the area between Eskifjordur and Nordfjordur. Plans in 2007 envisaged a 6,200m long tube with a T-8 profile and the project going to tender in late 2009 for award for construction to start in 2010. Geology is basalt with interbedded sedimentary layers.

Still in planning, the tunnel is now planned to be 7,800m long including the concrete portals, with a width of 8.5m and the standard 4.6m maximum height clearance. The project is almost ready to tender and bid call is expected in late 2011 for construction to start in 2012. However, due to the challenges facing the public funding route this three-year project may be postponed even further.

Arnarfjordur-Dyrafjordur Tunnel
Located in northwest Iceland, between the fjords of Arnarfjordur and Dyrafjordur, slightly south of the Oshlid Tunnel and also the T-junction of the Breididalur, Botnsdalur and Tungudalur tunnels, this project has been examining different alternatives at lower and higher altitude. The present plan is for a 5,300m long single tube with a T-8 profile. Geology is basalt with interbedded sedimentary layers.

Sundabraut Tunnel
The intended project site is the northern part of Reykjavik but the proposed 4,400m long, undersea double tube (T-9.5 profiles) scheme is competing against a bridge option and an immersed tube in the current difficult financial climate. The project is to be jointly developed by Vegagerdin and city. The geology in the area is basalt and palagonite – altered volcanic basaltic glass.

Mid-Austurland Tunnel
The project is located in east Iceland and could involve a series of road tunnels between the town of Egilsstadir and others on the coast, to the east and southeast. Studies have identified up to 14km of tunnel across the various alternative routes and tube combinations.

Depending on the elevation above sea level and number of links, there could be a single tunnel that is 11-14km long, or two tunnels with a combined length of 10-14km, or further alternatives. The scheme envisages a single tube with possibly an additional escape tube.

Hvalfjordur - expansion
The subsea toll crossing, which is slightly north of Reykjavik and provides a fast link to Akranes, was conceived as a possible scheme in the 1960s. Development finally got underway in the 1990s under a special purpose company, Spolur, which has public and private interests and was authorised by Parliament.

Almost two-thirds – 3,750m – of the tunnel is below the sea bed and at its lowest point the tube is 165m below sea level. The contractor was a JV of Istak, Skanska and Pihl & Son. Excavation was done over 1996-7 and achieved a best monthly advance of 517m.

A second, parallel subsea tunnel is being examined to meet safety requirements in future when traffic volumes appraoch 10,000 vehicles per day. No decision has been made on the financing structure. The tunnel might be built within the next 10 years.

Works at Muli and Straka
The Muli and Straka tunnels are the original tunnels in north Iceland that precede Hedinsfjordur Tunnel, and in fact were the coastal, single tubes – to the south and north – that eased access to Olafsfjordur and Siglufjordur, respectively. Increased traffic volumes and public demand following the recent opening of Hedinsfjordur Tunnel will determine how much of a bottleneck the older, shorter and smaller tubes may represent and which alternatives there are to improving traffic capacity into the area.

Talking Tunnels
In holding the presidency of the Nordic Road Association (NVF) and as a member of the Executive Committee of PIARC (World Road Association), Haraldsson is intensely involved, as he has been throughout his career, in the benefits of constructing and operating roads in Iceland.

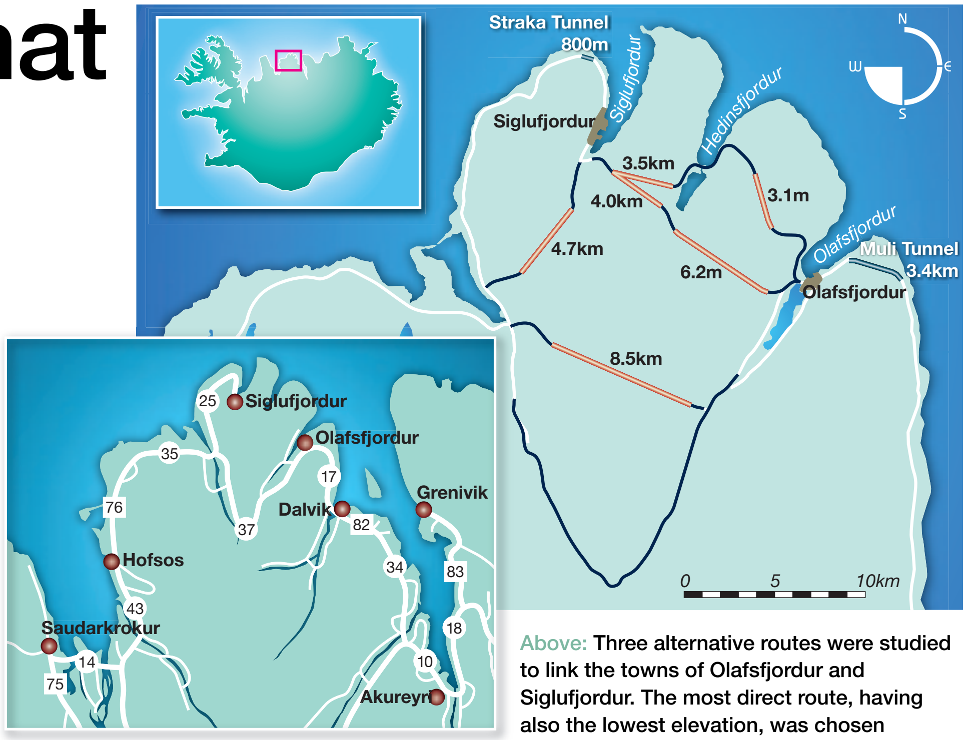
In 2012, Reykjavik will host NVF's Nordic Road Congress for the first time.

Iceland will benefit from, and continues to seek and need, good contact with the tunnelling community abroad, he says.

Left: **Difficult geology and groundwater ingress were significant aspects of drill and blast construction of Hedinsfjordur scheme, particularly on parts of Olafsfjordur Tunnel, which at 7,150m long (including portals) is also the longest, single tube, uninterrupted road tunnel in Iceland**

Ties that bind

A two-tunnel solution was chosen to overcome the coastal mountain barriers of North Iceland to connect the remote, former fishing hub of Siglufjordur with neighbouring Olafsfjordur and beyond



Above: **Three alternative routes were studied to link the towns of Olafsfjordur and Siglufjordur. The most direct route, having also the lowest elevation, was chosen**

Days gone by but within living memories and tales often recounted, and celebrated, the remote town of Siglufjordur in North Iceland was a powerhouse of the national fishing industry. The town grew and prospered on herring fishing and processing.

Boasting a sheltered harbour near the head of Siglufjordur valley, the town expanded where land meets water along the lower side slope of a long finger of a mountain ridge, part of northernmost area of the Trollaskagi peninsula. The fjord gives way to tough seas that hold the island speck of Grimsey, on the Arctic Circle and much farther beyond lies Greenland.

The town, though quite isolated by the mountains and their plunging, rocky coastal slopes, was for a time during the first half of the 20th Century the largest herring centre in Iceland and briefly, some say, the world. It had expanded rapidly from being a hamlet to housing 23 salting stations, five reducing factories and more than 3,100 inhabitants. Exports were important to the town, and the country. Good days, indeed.

But, the herring fishing then shifted focus a little as the waters off the east coast proved bountiful to new technology. Then more nations sought the shoals, leading to over-fishing and a collapse in the stocks. Competition and then the fall in herring numbers were a double-hit to Siglufjordur.

The population of the town has reduced by more than half since its peak, but there is still fishing activity and also support services are being increasingly developed to support the wider region.

In more recent decades a number of local people in generations coming up have moved to work elsewhere in Iceland, notably Akureyri and Reykjavik, and a few much farther afield, but many returning when possible to the bonds of family and friends. The town, like its neighbours – such as is Olafsfjordur – still offers vibrant community life.

Olasfsfjordur lies to the south east, separated by two mountain ridges and an uninhabited fjord – Hedinsfjordur. In the past, the town also benefited from the herring industry though its population is now less than 1,000.

A proud community in its own right, Olafsfjordur has always has been the smaller of the two towns. Historically, they relied mainly on boats, ships and horses for transport before motor vehicles helped to negotiate the coastal and mountain trails between the towns and other neighbours, and to travel farther beyond.

Left: **Hedinsfjordur Tunnel project will help overcome the restrictions to travel for the towns of Siglufjordur and Olafsfjordur due to the severe winter weather in near-Arctic region of North Iceland**

Above: **Looking north in Hedinsfjordur, the peaceful valley between the tunnels which locked by the two mountain ranges separating the small towns of Siglufjordur and Olafsfjordur**

Tunnels arrive

Efforts to improve access to Siglufjordur resulted in this corner of Iceland claiming the country's first reasonably long road tunnel, Straka (the actual first road tunnel is only 30m long, at Arnardalshamar). The Straka Tunnel was opened in 1967 and provides an 800m long, single bore link (with emergency bays) out of Siglufjordur to the north.

The second road tunnel in the area was a single tube bored to link to Olafsfjordur to the south. This 3,400m long long tube, Muli, was opened in 1991 and gave rapid and direct access to other towns to the south, such as Dalvik but especially Akureyri, the principal community in North Iceland. The portals were built big enough for the tunnel to be widened in future.

Now, this part of the country can also claim Iceland's longest road tunnel scheme – Hedinsfjordur Tunnel – which pierces the two mountain ridges between Siglufjordur and Olafsfjordur and is named after the fjord between the natural walls. Hedinsfjordur Tunnel was opened in October 2010 and has two single tubes, one through each mountain ridge.

The latest addition to this cluster of road tunnels was built to help improve links as well as safety, the economy and the social bond between the communities. Four years ago, in anticipation of the coming closer contact and ties from Hedinsfjordur Tunnel, the towns voted to join their municipalities under a new banner, Fjyallabyggd.

Alternative routes for tunnels to help improve road links between the towns were studied, but the scheme selected provides the shortest as well as the lowest altitude – and so least troubled by winter weather.

Direct, all-weather driving is now possible from Akureyri to Siglufjordur, and Hedinsfjordur Tunnel is already proving to be very popular, notes the Icelandic Road Administration, Vegagerdin.

It may not be long until the traffic capacities of the Muli and Straka tunnels need addressing, leading to either expansions or potentially fresh debates on how and where to improve links to the south.

Above: **Siglufjordur once was a major fisheries town and the new tunnel link will help boost mobility and contact both from and to its remote fjord location**

References

Icelandic Road Administration – www.vegagerdin.is

Community websites - www.siglufjordur.is, www.olafsfjordur.is, www.fjallabyggd.is and information (incl webcams) www.sksigli.is

Herring Era Museum – www.sild.is

Iceland's complex geology can provide for markedly varied tunnelling conditions and sometimes groundwater problems, such as faced on some earlier road tunnels and also more recently at Olafsfjordur Tunnel on the Hedinsfjordur project

Geological challenge

Sparsely populated Iceland sits on the northern run of the Mid-Atlantic Ridge where the Eurasian and North American tectonic plates are moving apart to be filled with extrusive igneous rocks. However, not all of the country is experiencing rifting and volcanism; the active zone runs diagonally through the land, cutting from the southwest to the northeast. This spine of the island is flanked by gently dipping basalts.

The Icelandic bedrock is dominated by subaerial basalts (100MPa-300MPa) but they are commonly faulted. The dominant features of the bedrock are the relatively thin layers of the basalt succession of porphyritic, tholeitic and olivine rocks, and the gentle dip of the strata.

The top and bottom of each lava layer are composed of fragments, resulting in the formation of porous breccia – scoria – which is usually well consolidated in Tertiary bedrock. The upper zone of a layer often has sedimentary deposits. Below, in the body of the solidified lava layer the rock usually has irregular columnar joints.

Most faults are sub-vertical and long these zones there is usually breccia of sheared and crushed rock that is well-cemented with the bedrock. There are also frequently basaltic dyke intrusions with horizontal jointing patterns.

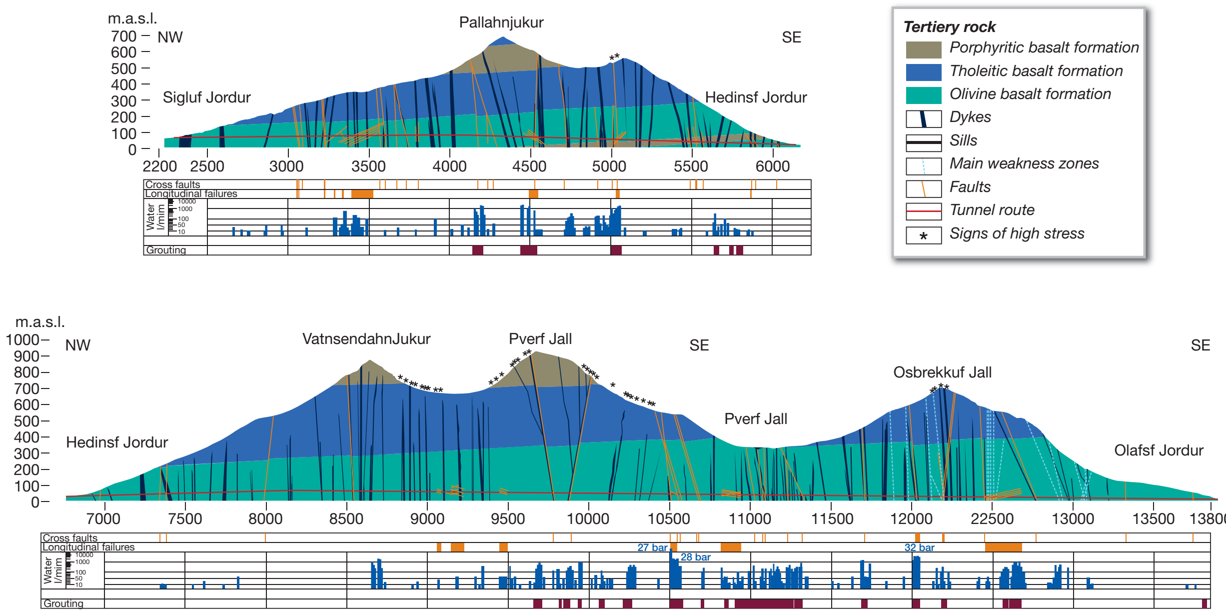
Groundwater typically runs along the lava contacts and cooling joints but the prime conduits are the faults and dykes through the layers, including sedimentary interbeds acting as impervious or semi-impervious barriers.

Groundwater Challenge

Many road tunnel excavations in Iceland have met fairly reasonable conditions but there have been occasions of difficult groundwater inflows, such at a basaltic dyke during excavation near the junction for Breidadalsheidi-Botnsheidi plateau scheme in the northwest of the country, on the Muli tunnel works in the north and most recently on the Hedinsfjordur Tunnel in the same vicinity.

Constructed in the mid-1990s, the Breidadalsheidi-Botnsheidi scheme comprises three branch tunnels – Breididalur, Botnsdalur and Tungudalur. Earlier tunnelling experience indicated there might be considerable but scattered inflows (up to 50 l/s per km). On the 2.9km long Botnsdalur drive the inflows increased significantly when excavation was 450m from the T-junction of the three tunnels – pressures began at 6-12 bar and eventually reached 19 bar; open joints were up to 10cm wide and connected, which resulted in little success with cement grouting – used for the first time in Iceland. Competent rock, relief boreholes and resumed excavation eventually helped take the drive forward.

However, on the 4.1km, long Breididalur drive, some 800m from the T-junction – and while anticipating major faults but despite using long probeholes – the right side of the tunnel unexpectedly collapsed on the uphill drive. The cold inflows from the crown were initially 2,500-3,000 litres per second but reduced to almost half the rate in a few weeks. The drive was halted and work



Left: **Cold, high-pressure water was frequently encountered during tunnelling**

focused elsewhere on the project. Eventually, an extensive combination of bolting and shotcrete support, drainage holes and channels, and grouting – including the use of chemical grout with polyurethane (PU), enabled the section to be passed. But the flow, while reduced significantly, has never stopped. Instead, it was piped to become a replacement spring-fed water supply for the town of Isafjordur, and is also now used for small hydropower generation.

A key lesson drawn from the project is that post-grouting with cement mix is very difficult, if not impossible, in high transmissivity basalts.

Groundwater at edinsfjordur Tunnel

Trollaskagi mountain range in the north of Iceland is formed by a complex of basic to intermediary rock types with sedimentary interbeds. The volcanic complex is of a lower Tertiary age, when short periodical lava eruptions alternated with short periods of volcano clastics sedimentation.

In the late 1980s, road tunnelling works in the area also experienced some groundwater problems, on part of the 3.4km long Muli project, near the small town of Olasfjordur. While the problems were somewhat similar to those later met on the Breidadalsheidi-Botnsheidi scheme the challenge of the inflow rates and pressures were not so great.

But the challenge of high inflows and pressures was met again in the region, on the recently-built tunnel at the other side of the Olafsfjordur valley – the almost 7km long tube, called Olafsfjordur ('Olafs') Tunnel, that is part of the Hedinsfjordur Tunnel scheme.

Olafs and its sister tunnel, Siglufjordur ('Siglu'), pass through mainly olivine basalt except for a relatively short section of porphyritic rock close to one end of Siglu. Along their alignments, the rocks are sub-horizontally bedded, disturbed by north-south trending tectonic faulting. As per the general context of bedrock in Iceland, along their alignments the rock mass holds many faults, dykes and joints. These made for often difficult – and sometimes exceedingly tough – tunnelling work in some sections.

The overburden height varies between 5-800m. Some rock bursting was anticipated along stretches of high overburden. Spalling occurred where the overburden was more than 500m, though began in Siglu with a depth of around 400m. The layered basalt lava succession in the tunnels with thin scoria and sedimentary interbeds resulted in mixed face conditions for a large proportion of the excavation.

While olivine basalt with sub-horizontal bedding is dominant in Siglu (with changing porosity and transfer to fine-grained facia) the tunnel has faults of 1-5m thickness. Groundwater conditions were easier and the temperature not as cold on Olafs but the challenge arose on the downhill drive and some cement grouting was done and occasionally some PU pre-grouting.

Geology along Olafs is mostly fine-to-medium grained basalts and partially volcano clastics, and there were some interbedded, nearly horizontal fine-grained tuff layers. The main joint sets are either perpendicular or parallel to the axis, but dip steeply. In many places the rock is heavily broken due to tectonics. The tunnel encountered many dykes but more brittle and broken than Siglu.

While the possibility existed for thermal inflows, and there was monitoring to assess any effects on geothermal water sources near some portals, in the event it was inflows of cold water that were encountered starting about 1km into the uphill drive from Olafsfjordur and continuing for a further 3.5km. In all, almost two-thirds of Olafs had groundwater problems.

Oshlid Tunnel

Just to show the variation in tunnelling experience in the complex geology of Iceland, relatively little water problems were met in construction of the 5.4km long mined section of Oshlid Tunnel (near Breidadalsheidi-Botnsheidi scheme).

The Oshlid tunnelling works did, however, experience some rock stability difficulties in sections where there were thick sedimentary layers between basalt layers.

Future challenges - Vadlaheidi Tunnel

To be constructed through the mountain east of Akureyri, the 7.8-8km long Vadlaheidi road tunnel is to be a single tube toll route.

If funding is agreed before the end of the year, Vegagerdin anticipates a prequalification call to contractors in 2011.

Geology along the tunnel alignment is basalt with interbedded sedimentary layers, and expected to be reasonably similar to that of Hedinsfjordur. Medium quality rock, in general, is expected with groundwater problems expected in some locations. The overburden is up to 450m.

Further core drilling is underway – 600m in total - in vertical and inclined bores - which follows earlier site investigation (2005) that performed 915m plus 200m of percussion drilling. Most of the core drilling is near the portals, others are further up in the mountain.

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Hedinsfjordur Tunnel – Key Statistics

	Siglufjordur Tunnel	Olafsfjordur Tunnel
Total length	3875m	7150m
Mined Section		
Mined section length	3650m	6925m
Mined cross section (T 8.5)	52.83m²	52.83m²
Mined cross section at widening	75.25m²	75.25m²
No. of widenings	6	13
Mined section volume	200,000m³	380,000m³
Portals		
Open cut (west portal)	125m	150m
Open cut (east portal)	100m	75m

* Note: Hedinsfjordur Tunnel has two single bores – Siglufjordur Tunnel and Olafsfjordur Tunnel

Below: **Metrostav divisional director Vaclav Soukup and Vegagerdin director general Hreinn Haraldsson at opening**
Photo credit: Stepan Soukup

planning and design process for the scheme took about 12 years.

Vegagerdin was assisted in the process by Icelandic design companies Mannvit, Verkis, Raftakn, Verkfraedistofa Nordurlands and Teikn. The geological consultant was Jardfraedistofan Reykjavik, and construction supervision was provided by GeoTek.

The tunnels broadly run northwest to southeast and their horizontal alignments are almost in a straight line apart from being offset slightly where they break out into the open to cross Hedinsfjordur valley. In terms of the vertical alignment, the roads slopes into and out of the valley at 3 per cent and the remainder of each tunnel drop from its crest at 1 per cent towards the towns.

Chainage along the alignment is measured from the northwest, Siglufjordur end where the new road connects with the existing. The route rises on rockfill across Fjardara valley at the head of Siglufjordur fjord into Skutudalur valley on the approach to Chainage 2.275km and the 125m long portal structure, constructed in open cut. In the mined tunnel the road continues to rise, at 1 per cent slope, to crest at Chainage 4.025km and fall off at 3 per cent towards Hedinsfjordur valley. The tunnel is named after the nearest town – Siglufjordur.

The alignment cross the valley on a rockfill embankment and crosses a river with a 14m long reinforced concrete single span bridge. From there it weaves up towards the next portal, and tunnel – Olafsfjordur ('Olafs') Tunnel – at Chainage 6.775km. It rises at 1.39% slope to crest at Chainage 8.9km. After this point it falls away towards the town of Olafsfjordur, exiting the portal at Chainage 13.925km and tying in to the existing road at Chainage 14.1km.

Above: **GeoTek's Bjorn A Hardarson and Oddur Sigurdsson provided the technical and contract supervision services for the client, Vegagerdin**

Hedinsfjordur Tunnel is a two-lane tube (one lane of traffic in either direction) with a cross sectional area of 52.83m² and clearance of Norwegian profile T 8.5. At regular intervals of around 500m along the tunnels there are widened sections, referred to and equipped as Emergency Bays. In Siglu Tunnel there are six bays and 13 along Olafs Tunnel, and they have a cross sectional area of 75.25m². Three of the bays are extra wide to be large turning areas.

The excavation would be undertaken by drill and blast method and guidance on support was for use of shotcrete and varying concentrations of rockbolts, as required. Iceland has a minimal, lighter

Right: **Jon Magnusson, client representative to the Hedinsfjordur project**

Above: **Ermin Stehlik (right), Metrostav's project manager for Hedinsfjordur Tunnel**

Above: **Johann Gunar Stefansson, general manager of Hafell, which joint ventured with Metrostav on the Hedinsfjordur project, being interviewed by local media at opening**

approach to support along the Nordic tunnelling lines, explains Bjorn A. Hardarson of Icelandic consultant GeoTek, which provided technical and contract supervision services to the client – akin to a Resident Engineer, monitoring but also advising on permanent support in the tunnels. He has extensive experience on road and hydro tunnels in Iceland. While wryly emphasising that the approach is not to build heavily reinforced pipes as tunnels, he notes that there has been a gradual increase in support.

Waterproof and frost protection (WFP) lining protection was to be installed, positioned proud of the rock with positioning bolts and leaving a water drip-zone gap. A thin layer of shotcrete would complete the permanent lining.

Procurement and construction

Procurement for the construction contract got underway in 2005 but it wasn't the first time. Four years earlier the project had been put out to tender in the EU zone and in 2003 the bids were opened. However, the Government postponed the construction phase of the scheme.

A prequalification process began in 2005. Tenders were issued early the following year. Five bids were received and were opened in March 2006.

A joint venture of Czech contractor Metrostav and local firm Hafell submitted the lowest tender and a contract for the construction works was signed with them in May 2006. The contract value was ISK 5.74bn (USD 91.53M in 2006 exchange rates). The next nearest was ISK 5.85bn and the others were more than ISK 6.1bn – the highest being almost ISK 9bn.

The contract is on a conventional unit price basis with the client responsible for quantities, ground conditions, key changes and standard Icelandic contract conditions for civil engineering projects. The technical specification and all contract documents were written in Icelandic since 2003 when the country moved away from FIDIC contract conditions.

Works started in June 2006 with Metrostav undertaking the underground works and Hafell the surface works, including open cut of the portal areas in preparations for excavation.

In total, the new route would add a direct route of just over 14km to the road network and link Siglufjordur and Olafsfjordur but until then the contractor had to face the circuitous journey between the towns like the locals – the shortest trip around the coastal and mountain valleys covering 62km in good weather but with harsh winter conditions the trip each way would stretch to 260km. As a consequence, the constructions camps set up near the portals were quite independent, and the construction supervisor operated in a similar fashion with two offices.

It would turn out that such commuting would be the lesser of their challenges. Very difficult ground conditions with large, high pressure inflows in Olafs Tunnel led to setbacks and tunnelling challenges which came to be understandable to all concerned as creating delay against the original programme to complete the entire project by late 2009. The groundwater problems were eventually overcome through persistence and extra application of expensive chemical grout. The tunnellers' tenacity brought recognition to Metrostav, from the client and construction supervisor and the communities.

Hardarson notes that the inflows caused 'huge work' and was the prime challenge among others that included high-pressure, low water temperatures and achieving grouting solutions in the jointed rock. While aspects of these conditions have been seen in some other road tunnels, he says these were 'difficult conditions'.

A further challenge came from outside during the contract period, however, when the economy of Iceland and its currency suffered their own tectonic shocks, hitting the exchange rates.

Local engineering nous was key to a fresh approach on the WFP lining installation, including positioning bolts. The works were undertaken by local firm VK Contractors – their staff also worked on the concrete tunnel portal construction using its own, custom-made travelling formwork. The name behind the technical preparation and innovations is Helgi Valur Einarsson, managing director of VK. Hafell completed the drainage and road surfacing works through the tunnels.

Construction was completed in September 2010, and Hedinsfjordur Tunnel was officially opened on 2 October.

References

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VK Contractors – www.vkc.is

GeoTek – www.geotek.is


The best monthly advance on the 3,650m long, mined section of Siglu was 302m


The average progress rate on Siglu in 20 calendar months was 200m, allowing for planned stoppages

Then, in Hedinsfjordur valley, the activity would be joined by a carefully landed from the sea construction plant for the cross-valley earthworks that would provide the route up to the new portal opening on the opposite mountai range. Then, Siglu's tunnellers would commence blasting at Olafs, driving from the opposite direction to that already underway.

Starting at Siglu

Blasting of Siglu tunnel began in September 2006 at Chainage 2.400km along the new route from the existing road near Siglufjordur. The open cut had been made behind where, at Chainage 2.275m, would later be built a 125m long concrete portal. The drive was to advance on an uphill slope of 1 per cent for approximately 1.6km to crest, and then the excavation progress down on a 3 per cent slope for approximately 2km, to breakthrough at Hedinsfjordur valley.

Excavation started well. The drive passed a geothermal area that Siglufjordur draws hot water from without causing any known disruption to the flow.

Geology along the alignment comprised olivine basalt for the majority with some porphyritic basalt towards Hedinsfjordur and the final, downhill stages of the excavation. There were regular, and some large, sub-vertical dykes along the majority of the alignment, and faults.

Both the dykes and the faults were found to be more concentrated after about 700m into the drive. The faults were particularly intense around chainage 3.3km, where there were longitudinal failures and the first groundwater inflows of note began. Beyond that zone the flows stopped, arising only along relatively short sections at further faults at the middle of the tunnel.

Three-quarters along, though, there were some more longitudinal failures of the rock, again caused by sub-horizontal faults and more inflows began. It was approaching this portion of the drive that the first grouting was needed – in three sections, apart from some needed closer to the end. Overall, Siglu had proved to be a reasonable tunnel to drive by the time Metrostav holed through to Hedinsfjordur in March 2008, only to catch a surreal sight: from underground the tunnellers were looking out at a green play of faint, wavy bands of light in the sky – the Northern Lights.

'Pretty good' tunnelling

The relative ease of tunnelling in Siglu gave no hint of the massive geological challenges that would be met in Olafs. However, Iceland is known for its radical variability in geology, some road tunnels have large groundwater problems while others let tunnellers drive forward, possibly with some wetness or stability issues. Difficult to predict, although surface features such as dykes slanting up from the depths can give some potential insights, though nothing definite.

Left: **There were some groundwater problems for Siglu but nothing like on its sister project, Olafsfjordur ('Olafs') Tunnel**

While Olafs would add its name to the annals of Icelandic tunnelling difficulties, it was Siglu – which was 'relatively pretty good', says Ermin Stehlik, project manager with Metrostav – that was to be the better run underground, giving no warning of what lay deep in the hillside of the other valley. Even what groundwater there was in Siglu, at between 10 and 20 degrees C, wasn't as cold as that to be encountered in high-pressure jets in Olafs.

Yet, it was fortunate, too, that as the face advanced ever closer to Hedinsfjordur and to the mountains that were to be blasted through for Olafs, there was not a general rise in significant groundwater problems; not something to be easily faced in a downhill drive. But there was some inflow, which was dealt with by a system of provisional sumps with automatic pumps.

Two grouting solutions were used to stem water inflows. A total of 460 tonnes of cement grout was used for pre-grouting on most inflows using Atlas Copco's UniGrout E 45 two x 100 pump. In rare cases, when the water remained close to the face despite the regular probe hole drilling, polyurethane (PU) resin pre-grouting had to be used. In total, the downhill stretch called for 40 tonnes of PU chemical grout.

In a few instances where there were large inflows of groundwater from probe holes the situation did become critical, requiring the Sandvik Axera T11-315TCAD drill rig to be removed from the face. Overall, these were exceptional. The advance rates achieved in these occasional wet conditions were admirable, says Metrostav.

The biggest problem encountered in the downhill section were caused by water shooting out of fissures after blasting and at times excavation had to be suspended and the fissures sealed. It was a difficult operation using PU-soaked rags driven into the fissures by wooden wedges or bunched inside 'cushions' locked into the rock by bolted steel sheet plates over wider openings.

When fissures were successfully sealed, a borehole would be drilled close to the source of the now-blocked flow, then a hydraulically expanded packer would be inserted. The packer would help to fill the fissure in the face area with a PU material, waterproofing the rock wall to enable longer boreholes to be drilled farther ahead for cement pre-grouting. The approach prevented free-flow and loss of the cement suspension.

Tunnelling

The excavation sequence usually involved drilling two 51mm diameter probe holes in the range of 25-32m beyond the face, ensuring a 6m overlap between each investigation into the rock ahead. Based on volume, pressure and temperature of the groundwater in the probe holes there would be a joint decision by Metrostav and the client's technical and contract supervision services engineer, from GeoTek – 'The Supervision' - on whether grouting would be required before proceeding.

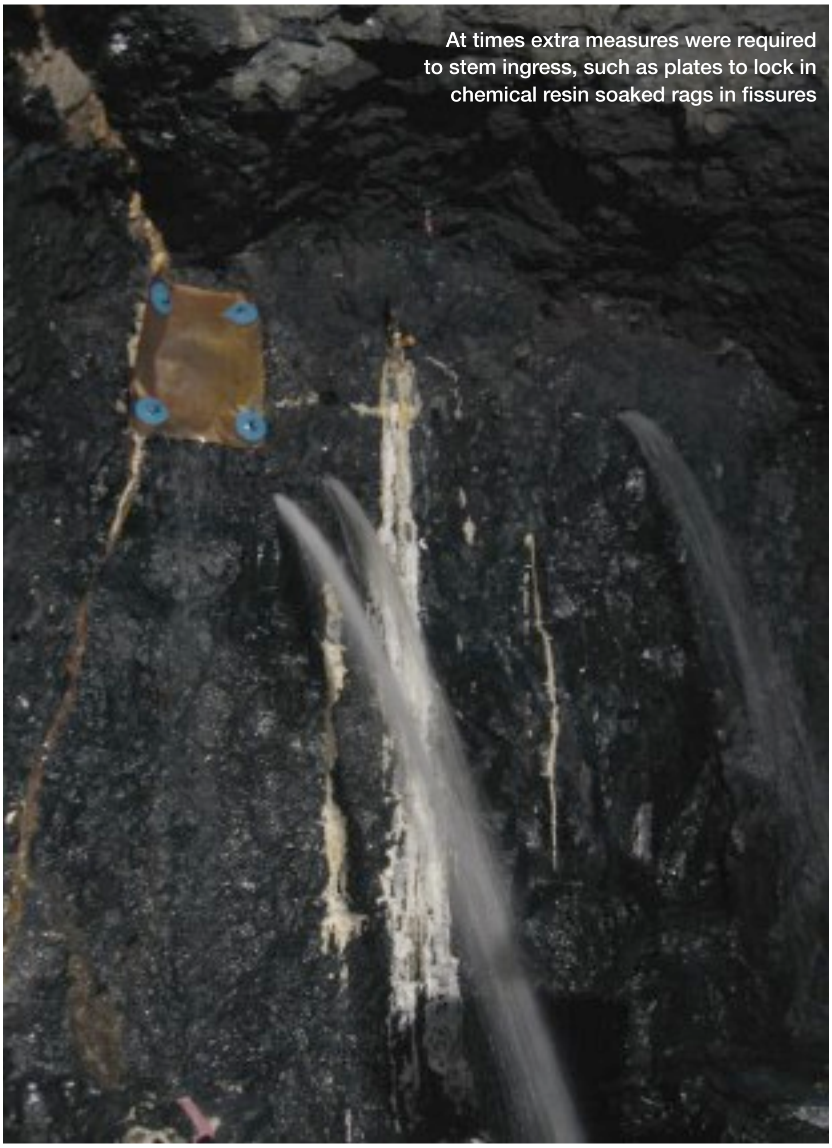
A Sandvik Axera T11- 315TCAD drill rig was used for both drilling the probe holes as well as the face pattern of 48mm diameter blast holes. TCAD is a semi-automatic system using a software program to measure the position and the direction of a drill bit using laser to correlate the drilling pattern and boom positions with the tunnel alignment coordinates. The boom is then moved by the operator to ensure the drill pattern remains accurate.

In both Siglu and Olafs the rounds were usually drilled to the full length of 5.27m, giving a pull of between 4.7-5m. The round lengths were reduced to 3m when more difficult ground conditions were met.

Blast holes were usually packed with Titan 7000 blast emulsion – now renamed Civec – supplied by Orica Mining Services. A Mini Site Sensitized Emulsion (SSE) pumping unit completed the charging after being transported to the tunnel face by a small truck. The Mini SSE system meant the emulsion could be pumped into two holes at the same time. It also allowed the operator to change the charge according to the type of blast hole.

The emulsion proved effective for blasting in hard and brittle rock but when more porous patches were met the crew used classic explosives. In some cases a combination of both types of explosives was employed. The 25g Nobel Prime detonator amplifiers were chosen as boosters and inserted into the blast holes together with non-electric detonators during the emulsion pumping.

Mucking out was done by Komatsu



At times extra measures were required to stem ingress, such as plates to lock in chemical resin soaked rags in fissures

Loading and mucking out worked well

dumpers, mostly with 35 tonne capacity, which were rented from local company Kraftvelar. Spoil was removed to temporary and permanent dumping sites located close to the portals, while suitable material was put in a crusher for rock fill to await the later road works. The dumpers were loaded by Broyt C600Ws with 3.4m^3 shovels. As a back-up, Volvo 180E wheel loaders were available onsite.

Successful completion

The drill and blast work in Siglu progressed with relatively few difficulties. Like on Olafs, the site personnel and crews – those in charge, the foremen, the miners were all Czech and lived in the adjacent town, Siglufjordur. They worked two 12-hour shifts on a six-day week. Catering was provided on site The week ran from Monday morning to Sunday morning.

In almost 20 months of tunnelling they had achieved an average monthly advance rate of 200m. The record month on Siglu was 302m.

Above: A well earned celebration at Siglu on holing through, in March 2008, to Hedinsfjordur valley between the tunnels under construction

Key Personnel – Siglufjordur ('Siglu') Tunnel

Client's Representative – Sigurdur Oddson and then Jon Magnusson

Supervision (GeoTek) – Bjorn A Hardarson, Oddur Sigurdsson

METROSTAV

Project Director/Manager – Ermin Stehlik; started as Consultant in September 2006, then became Project Director in October 2007; initial phase PM was David Cyron

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HAFELL

Project Management: They were, consecutively, Magnus Jonsson, Gudmundur Bjornson and Valgeir Bergmann

Driving the Olafs Tunnel was the longer and the tougher challenge by far of the two road tubes on the Hedinsfjordur project, the main cause being groundwater

The excavation of Olafsfjordur ('Olafs') Tunnel in the Hedinsfjordur road project, in north Iceland, is a story about water. Lots of water – cold, often at high inflow rates and high pressures. Driving through basalt with sedimentary inter-beds, the inflows mainly came through jointed dykes and fault zones scattered and clustered along the alignment.

Yet it hasn't been the highest groundwater inflow experienced in a road tunnel excavation in Iceland. That was on the Breidadalsheidi-Botnsheidi scheme in the north west of the country in the mid-1990s and it is still flowing. The engineers established a work-round as a permanent solution that channels off the water, for industrial and water supply use, and enabled the project to complete.

But those Metrostav tunnellers who constructed Olafs, while not experiencing rates as high, can claim to the largest inflow that has been effectively stopped during construction of a road tunnel in Iceland. Hence, the recounting of the tunnelling experience at Olafs is also a story about grout, lots of grout – cement, of course, but especially chemical resin which, unusually, would turn out to be needed in large volumes.

Geology

The geology of the mountain range through which Olafs passes comprises sub-horizontal basalts, mostly fine-to-medium grained, with porphyritic over tholeite and the olivine formations – the tunnel alignment passing entirely through the latter, except for some volcano clastic sediments, such as scoria and red sandstone. In addition, within the basalt formations there are some interbedded, near horizontal layers of fine-grained tuff.

The main joint sets are either perpendicular or parallel to the tunnel axis, but are steeply dipping. In many places the rock is heavily broken due to tectonics. The tunnel encountered many broken, brittle dykes.

There are geothermal water sources on the portal areas nearest each town, and there was the possibility for thermal inflows. But it was the opposite that was the problem – cold water which, in the worst zone, was believed to be linked through fairly open joint channels up to the ground surface with the resulting pressure, flow and chill. The danger in Olafs was that heavy inflows could reduce the natural water pressure which is utilised for hot water supply.

The surface terrain has three mountain peaks – Osbrekkufjall and the two highest, Pverfjall and Vatnsendahnjukur – with two valleys in between, the largest being Sydrardalur and also the lowest in elevation and holding the Sydra stream. It was this stream that, it is believed, is possibly linked by open joints to the strata at depth and consequently charged some of the inflows to the tunnel excavation.

Left: Groundwater problems quickly arose in Olafs, just over 1km into the first drive and then didn't let up for another 3km. Soon chemical grout was required

However, while indicative information was obtained from surface studies it was not clear from those examinations and the limited core boreholes what was the nature, extent or detail of disruptions to the rock mass at depth. The overburden on the tunnel alignment at Olafs was up to 800m.

In all, almost two-thirds of Olafs had groundwater problems. Geological mapping of the features encountered was done by Mestrostav by Prague-based Arcadis Geotechnika, its geologist being permanently onsite.

The final geological section, after construction, shows the highest concentration of faults in the southeast, or early excavated half, of the tunnel alignment. Over this stretch there are many dykes, too, especially below Sydrardalur valley and then in the north west third of the tunnel, commencing below, and being most concentrated at, the other valley, between the two highest peaks and where overburden is most.

Getting underway

In mid-2006, Metrostav began assembling the team of 90 Metrostav workers (70 specialised, 20 engineers) in preparation to be based in remote North Iceland to build the Olafs and Siglufjordur ('Siglu') tunnels for the Hedinsfjordur road project. The company thought it might be reasonably possible (and was somewhat hopeful) that with its effective organisational skills and extensive construction experience it would be able to complete the works programme, scheduled to take just over three years, a little earlier.

But the unexpected ground conditions with cold inflows at Olafs would prove to be of such scale and occur over such protracted distances, that the contractor's initial goal would not prove to be achievable. The tunnelling difficulties being experienced were examined by the client – the Icelandic Road Administration (Vegagerdin) – and its contract and technical services supervisor, consultant GeoTek.

Once the nature and scope of the problem had been established, it was agreed to be outside the contractor's accepted and competent approach, as the client carried the geological risk as with other road tunnels in this land of variable and tectonically disrupted geology, the unit-price contract meant that the challenge, and focus, was to find the best engineering solutions.

As with practice on each blast along the drive on Olafs and Siglu tunnels, there would be discussion between Metrostav's engineers and the supervisor to determine the agreed nature of the ground conditions and problems at specific chainages, the potential solutions to try or step-up to next, and also the degree of permanent lining support required.

The 'Scandinavian Method' of tunnelling was used, the design and specifications based on Norwegian practice was to maximise installation of permanent support during the first pass of the excavation phase, while those support measures are themselves to be minimum in relation to the length of round, slightly over 5m. There were two support phases, first the initial support during excavation and then the permanent after breakthrough. Primary and later secondary layers of steel-fibre shotcrete, each 50mm-80mm in thickness, were applied. Permanent bolting used SN and CT bolts.

As the works advanced, and various solutions were tried and implemented, there was growing recognition and admiration

Left: Olafsfjordur ('Olafs') Tunnel on the Hedinsfjordur road project, in north Iceland, called for almost 7km of mined tunnel to be blasted through a mountain range with basalts and sedimentary inter-beds that turned out to have many jointed dykes and faults

Above: **The severe groundwater problems sometimes seeped and soaked the excavation face …**

from the experienced Icelandic tunnel engineers for the dedication and steadfastness of Metrostav – the sheer persistence of the company itself and the hard work of its engineers to ensure, and secure, the delivery of Olafs, and so the Hedinsfjordur project. For conditions were relatively easier on Siglu. The shorter tunnel was not throwing up such extreme groundwater conditions as being repeatedly met in Olafs.

There was a concern, however. When the Siglu drive crested on its vertical alignment and then began blasting the downhill slope to advance closer towards Olafs, - albeit separated by a valley – might groundwater problems appear then? Fortunately, in the end, Siglu was completed without such major difficulties arising although in its last stages there were some inflows, resulting from dykes and faults.

The first hurdles

Excavation started in November 2006 on the almost 7km long mined length of Olafs. The drive would be approximately 5km uphill from the portal at Olafsfjordur. But it was not too long – approximately 800m into the drive that the first notable groundwater difficulty was encountered. Then, within a further 160m the ingress had reached more than 2000 litres per minute or approximately 33 litres per second, pressures were 10-15 bar and the water temperature was as low as 2-3 degrees C.

At this point there were no faults and the first mountain peak and valley hadn't yet been reached overhead; dykes were the problem. The contract provides for the possibility of pre-grouting to help seal off leaks using cementitious or chemical methods with Metrostav and the supervisor having jointly assessed inflow from a pair of probe holes. The threshold inflow rate was set as 600 litres per minute (10 litres per second) to help determine between pre and post-grouting in relation to excavation. Once a pre-grouting operation had been done another, shorter pair of boreholes would be drilled to check how well the leak

Below: **… and at other times, and from other ground, erupted as a high pressure jet**

Above: **…or many jets as more difficult locations was reached**

had been stopped.

Therefore, just over 1km into the drive it was decided to commence grouting in the front zone of the face by using cementitious grout. However, this proved unable to seal off the inflow and the contractor and supervisor agreed that polyuerethane (PU) resins be tried instead. Following confirmation of products being certified as suitable for use in area of health and environmental sensitivity, these were supplied by Minova. They had been used elsewhere in Iceland, including tunnelling on the Karahnjukar hydro tunnels then under construction in east of the country.

The chemical grouting set consisted of GX-45 II pumps, BVS-40K hydropneumatic packers to fix the grouting rods in the boreholes, and CarboPur WF and WFA two-component polyurethane (PU) resin including CarboAdd Thix 1 and 2 accelerators. Minova trained select Metrostav crew in both the theory and practice of working with the chemical grout systems, which would require procedures (such as pre-heating) as well as the drill patterns to be adjusted to handle different inflow rates, geology and technical condition for application of the product.

In addition, Metrostav was able to call upon the services of a grouting consultant, Tomasz Najder, as recommended by the client's supervisor and also working then in Iceland dealing with inflows challenges on the Karahnjukar tunnels. Metrostav's project director, Ermin Stehlik, says due to those many challenges on Karahnjukar the contact with Najder was often phone, fax or email.

The contractor also installed intercepting traps both within the tunnel and at the portal to catch any chemical leaks, if necessary.

At 1km into the drive on Olafs, therefore, the approach was recommended to be to drill 16-18 probe holes ahead of the face, of 12m-20m lengths, from around its circumference. The holes would then be used to inject the PU grout, which was to form a protective ring-barrier against inflows. This approach was used over a section of approximately 80m and took 1.5 months, completing in July 2007.

Even tougher ahead

However, the following month, more than 800m further into the drive, the PU grouting was to be called upon once again for probe holes had found groundwater pressures up to 30-32 bar, and there were fissures and cracks up to 500mm wide in the rock mass ahead.

A higher performance SK-90 rotary gear-type pump was introduced, plus a suitable compressor for compressed air, and Geofoam foam-producing resin was added to the materials options. Dedicated boreholes would be added to the drill pattern to pierce and attempt to fill the larger voids with the foam. A CT-PM high performance electric pump was also prepared on site, though eventually was not called upon.

There was also the challenge of having a sufficient stock of the PU resins for both the application rate, and volumes needed, would be higher than earlier in the drive. The time taken to source and have delivery to near the Arctic Circle on Iceland of repeated, large truck loads of non-stackable cans of PU resins would be a factor that led to further delay in the programme.

Then, about 340m further ahead, a fault was encountered with pronounced tectonic breccia of stones up to 500mm with clayey-sandy matrix. First met on the left of the face, the breccia zone was exposed to take up the entire left half of the area as the drive advanced only 4m. On the right was altered scoriaceous basalt with a sedimentary inter-layer. The clayey fill was blocked the drill bits. Large inflows of 600-1200 litres per minute were found during rock bolting beforehand and from probe holes. No jets of water came out the face, only a continual extreme wetness, which prevented application of steel-fibre shotcrete.

As a consequence, the solution concept was to view the material as soil. An array of nine 12.6m long, 51mm diameter boreholes were drilled, splaying outside the profile area and PU resin injection significantly reduced the flows leaving the remainder to be drained by intermediate boreholes. Mesh and shotcrete were applied. Where rock bolting met water, there were parallel bore drilled for drainage set about 500mm away, a packer fitted and grouting undertaken that would enable the rockbolt to then be filled with grout.

Further ahead, worse was to come – single probe holes unleashing cold water flows of up to 2500 litres per minute with relatively constant pressures of 24-29 bar. The inflow was coming below Sydrardalur valley where the basalt overburden was found to be intensely fractured. This would be one of the worst areas on Olafs. Fissures were 2-50mm with clayey fill and there were crushed zones with clearly defined slickenslides. Beyond this section there was a tectonic breccia of stones in clayey sand.

However, in July 2008, on a section of the tunnel there was a point where inflows were so severe, reaching about 500 litres per second that pre-grouting was impossible and the tunnel was subsequently flooded, but only for a period, whereas the inflow decreased significantly within a few days.

Stehlik says: "The difficult part was that sometimes we thought that the worst was behind us, everything worked well, but all of a sudden we would hit the water again." He adds that tonnes of PU resin was being used daily and there was the further incredible sight of large stocks of the expensive, but highly effective product, rapidly depleting, knowing it takes six weeks to get more to Iceland.

Above: **A drive from Hedinsfjordur valley to blast Olafs from the opposite direction started in May 2008 but at a shallower slope than first planned to give longer distance uphill and avoid any downhill grade risk with groundwater before breakthrough underground**

Completing the challenge

Breakthrough in April 2009, meeting the Siglu crew who had crossed the valley and blasted on an uphill drive to close the gap. However, given the experience of Olafs, should they have reached the crest first then there was the risk of proceeding into a downhill slope.

So, with this potential foreseen early on and no-one wanting a submerged face, it was agreed with the client sufficiently in advance to drop the vertical slopes for the drive in Olafs from Hedinsfjordur valley, and consequently shifting the crest to the south east by some five hundred metres, and so continuing giving both crew uphill drives.

Two Sandvik Axera drill rigs were used on the project, one per tunnel, and drilled a total of 40km of holes for pre-grouting and 32km of probe holes - both with 51mm diameter. The blasting holes were 48mm diameter. The drill rigs proved very reliable and were a good choice for the conditions, said the contractor.

With no access adits along the drives, the ventilation system was designed as a separate blowing set up. On Olafs it was provided by 1 x 1800mm and 1 x 2100mm diameter non-reinforced ducts and two axial Cogemacoustic, type T2 180 ventilators with frequency converters for regulation suited to tunnel length.

The absence of an adit also presented a challenge to move construction equipment to the face as well as mucking out. A dumper was used for transport. For mucking out, initially working with a loader brought a few problems, such as high breakdown rate, mainly with operator training. That was overcome and loader performance is much better than wheel loaders, says the contractor. It was used for excavating the invert and the first scaling operation.

While the best month's advance on Olafs was 330m – higher than in Siglu – the average was reduced to less than 180m over the 3km stretch of drive with inflow problems.

After negotiation between the client and contractor, the extra time needed and financial cover for the additional works dealing with the severe groundwater complications, the target for completing the

Right: **Outside the water froze and it snowed, inside the tunnel and the work went on**

entire project was moved to the end of September 2010 from an original date of late 2009. There was also a separate agreement by the client that helped to partly offset the exchange rate difficulty brought by the economic problems that shook Icelandic and the consequent drop in the value of its currency.

The Hedinsfjordur road project was officially opened on 2 October.

The challenges faced by Metrostav and the solutions used were discussed in February 2010 at a presentation by Ermin Stehlik to the British Tunnelling Society (BTS) in London and since have been shared with visiting tunnellers to Prague.

Recalling the BTS talk, Martin Knights, global tunnelling director with Halcrow Group and past president of the International Tunnelling and Underground Space Association (ITA), praised the presentation for being both highly informative and enjoyable. Not least, the assembled tunnellers were presented with an uncommon addition to a BTS talk – video footage of tunnelling work under extreme conditions, made at a face in Olafs where there was heavy groundwater inflow, and all set to classical Czech music composed by Smetana. The soundtrack of AC/DC accompanies another video presentation showing blasting and other activities in Olafs Tunnel.

Knights says: 'The Project presentation was first class and respected the audience's needs— to be informative, interesting, honest (in that problems were clearly explained as were the consequential solutions) and it was very entertaining.

'The project presentation had many sub-themes regarding the construction of the underground works including water ingress problems. These issues were well explained – even with the appropriate musical background!

'Clearly the speaker had prepared the presentation well and had mastered the art of storytelling of a complex technical subject for an English speaking audience. No mean feat!

'BTS is indebted to Mr Stehlik for a well researched and presented presentation—in fact the presentation was so comprehensive there were very few questions forthcoming after Ermin`s presentation—he should take that as a compliment!'

Key Personnel

Olafsfjordur ('Olafs') Tunnel

Client's Representative – Sigurdur Oddson and then Jon Magnusson

Supervision (GeoTek) – Bjorn A Hardarson, Oddur Sigurdsson

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Assistant - Vaclav Pavlovsky

Surveyor - Jan Mleziva

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Gang leaders: Pavel Imrich, Pavel Rudlof, Frantisek Zifcak

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HAFELL

Project Management: They were, consecutively, Magnus Jonsson, Gudmundur Bjornson and Valgeir Bergmann

Left: **Celebrating the underground breakthrough, in April 2009, when two uphill drives met completed the challenging excavation of Olafs**

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The Ground Support Company

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Portals and protection

Work on construction of insitu concrete portals and installation of water and frost protection (WFP) benefited from a gathering of innovative ideas and systems

Above: **Olafsfjordur Tunnel, at the south east end at Olafsfjordur town, where steel reinforcement was being assembled at the end of 2009 using a multi-platform gantry arrangement on a flat wagon to help with insitu concrete portal construction**

There's a name that keeps coming up, that of a go-to practical and resourceful Icelandic engineer and craftsman who has won the praise of many and is experienced with tunnels. He came up with fresh concepts to use on the project that gathered innovative ideas and systems to help construct insitu concrete portals in exposed, harsh, and cold conditions and then developed an efficient manufacturing-style approach to installation of water and frost proof (WFP) lining in the tunnels.

'Helgi', is all that needs to be said, but his full name is Helgi Valur Einarsson.

For construction of the concrete portals he came up with a system like a port-style straddle crane to move assembled arches of steel reinforcement and shutters. The formwork for casting the sections was design and produced in Prague and supplied to Iceland by Metrostav.

In the tunnel, a multi-platform gantry was created to have numerous operations underway consecutively for measurement and then installation of the WFP positioning bolts to achieve the finished profile for the lining, later to be shotcreted, despite the varied cross-section of the drill and blast excavated tunnels.

During the project, he helped to establish and co-owns VK Contractors, which worked under a subcontract for the Metrostav-Hafell joint venture contractor. Other co-owners are Johann Gunnar Stefansson and Skarphedinn Omarsson.

In the portal and open-cut works, VK Contractors was able to speed up the work cycles and increase both efficiency and productivity compared to the initial approach, resulting in much-needed cost and time savings, benefiting the construction programme.

Concrete Portals

A total of 450m of concrete portals were constructed insitu for Hedinsfjordur Tunnel project – half for each of the two tunnels, Olafsfjordur ('Olafs') Tunnel and Siglufjordur ('Siglu') Tunnel, that comprise the new road link. Olafs has portals of 150m and 75m lengths, respectively, while those at either end of Siglu are 125m and 100m.

In each case, a single tunnel has a total of 225m of concrete portals to help keep access open especially in the extremely heavy snows in this northern coastal part of Iceland, which is not too far from the Arctic Circle.

Originally, the portals were to be constructed traditionally by building the steel reinforcement into the formwork and using a number of shutter sections lifted by mobile crane. However, bad weather was interfering with the process, such as ice build-up and snow entering the formwork, and scaffolding was needed every time for assembly. Reinforcement placed against formwork also caused extra wear and tear.

Helgi and his team came up with a new approach of concurrent activities, leaving curing time the prime time constraint. The system allowed the portals to be constructed insitu in 12m long sections, joined by a specially-designed membrane. Each 12m section took up to three days to construct. The total volume of concrete used for their construction was 5007m^3 and the tonnage of steel reinforcement was 520 tonne.

Portal construction begins with preparation of the reinforced concrete foundations strips while, not far away, a specially-built, oval-shaped long multi-platform gantry is used as support for assembling of the steel reinforcement into arches matching the tunnel geometry. The gantry, running on wheels, then transports the reinforcement to the casting site where it is lifted by a horseshoe-shaped gantry crane and placed onto the awaiting full-size, inner formwork shell.

The crane then lifts the complete outer formwork in its entirety and places it on top of the reinforcement. Following bolting and sealing, the shuttered rebar is ready for concreting. Meanwhile, the multi-platform gantry is being used to begin assembling the next arch of reinforcement.

After the outer formwork is struck it is lifted by the crane, washed down and oiled, and then brought back to protectively cover the thick canvas sheets that have been placed meantime on the hardening concrete to limit heat loss. Later, the inner formwork is struck and lowered for cleaning

Above: The horseshoe-shaped gantry crane running on tracks was used to lift reinforcement into place for the next stage of portal construction

Below: Final preparations are made before the horseshoe-shaped gantry crane transports the outer formwork into position for the last stage of insitu concreting works at the portal. Plastics tubes protrude up from the formwork to receive the pumped concrete

and oiling before being put into a new position for construction of the next section of the portal – and, still having some heat from the curing concrete, there were few if any problems with snow and ice.

Shorter time and simpler processes meant fewer man and machine-hours, less risk of weather interference and better durability of equipment, and so overall better use of resources. The smooth, multi-activity operation became known as the NSH system – Non-Stop Helgi.

WFP Lining

Following the success with the manufacturing approach to concrete portal construction, the team became involved in the challenge of the WFP lining – how to efficiently and rapidly get the required length of holding bolts in the correct positions in each and every location in the tunnels, for nothing was standard.

Metrostav surveyors used SetOut software from Leica for setting out the bolt positions. This is based on surveying the cross-sections of the excavated profile and recording the data by chainage. Then, knowing the finished profile sought, software can calculate the necessary lengths of bolts for each position.

The challenge, then, was two-fold – accurately drilling at the necessary bolt positions to the required lengths, and organising a system to ensure the right bolt was where it was needed to hand as the installation process moved along the tunnel. Again, a multi-platform gantry system would play a role.

However, due to specialist, and expensive, equipment for bolt positioning and drilling not being available from Norway, an alternative – and successful – solution was elected: to carefully use the Sandvik Axera drill rig. About 46,000 bolts were installed, each 16mm in diameter. The only problem, especially during the starting period, was consumption of special drill bits, because the small diameter is not so commonly produced or used.

Then, the WFP foam lining, supplied by Skumtech of Norway, would be prepared for placement. To match the open deck transport available, the maximum length of the 2.7m wide sheets was 11.4m. The system requires a 300mm overlap in all directions – the key to prevent cold air getting into the void that is left deliberately between the lining and the excavated walls for groundwater drip space. Where there are spots of slightly more, concentrated flow, extra protection such as stainless steel sheets or GSE membrane is used to stop the WFP foam being locally weakened and ruined.

Under the brand name of Sleipnir, VK is exploring a patent for the system used for the WFP installation at Hedinsfjordur. VK anticipates it could also be useful in tunnel repair work.

Above: Portal construction at Olafsfjordur in its final stages in February 2010, with the outer formwork removed while the inner formwork remains in place.

Above: A new survey, calculation and organisational system was developed to speedily undertake installation of each individually-sized WFP positioning bolt at Hedinsfjordur

It's Open!

The opening of Hedinsfjordur Tunnel brought myriad celebrations and activities. The eagerly awaited new road link is popular and has strengthened yet further the bonds between the communities of Siglufjordur, Olafsfjordur and towns beyond

On the morning of 2 October, 2010, as the wind picked up and clouds brushed the top the mountains in Trollaskagi area of North Iceland, a small group of cross-country skiers came down the main road in Olafsfjordur on their pre-winter, road-running roller blades and kept going, into the tunnel that was to be officially opened that afternoon.

They were followed by a spread of long distance runners in a new race, then some cyclists, and locals out to walk and, of course, some cars.

The snows would be here before long and the tunnels linking through to Siglufjordur, which had been eagerly awaited for a long time, and were greatly supported by both communities and many more people, just had to be explored on this exceptional, landmark day.

Hedinfjordur Tunnel was to be officially opened.

Those who came from far and wide that day from other parts of the north region and the country and also from overseas, would see another sight as they made their way through either of the two tunnels that constitute the Hedinfjordur project - Olafsfjordur Tunnel and Siglufjordur Tunnel. There was a scarf, a wandering line of woollen multi-coloured links sewn into a chain more than 11km long, which had been patiently made by hundreds of hands over many months, in Iceland and beyond, and laid along the side of the road and tunnels.

The two small and vibrant communities of Siglufjordur and Olafsfjordur had been joined.

Opening Celebration

When the afternoon came round the clouds were parting and some sunshine found hundreds of people gathered in the normally still, uninhabited and peaceful valley between the tunnels. They had come by special buses and cars and included the President of Iceland, Olafur Ragnar Grimsson, and the Transport Minister, Ogmundur Jonasson, and Finance Minister, Steingrimur J. Sigfusson – for the official opening.

The representatives of the Icelandic Road Administration (Vegagerdin) were led by director general, Hreinn Haraldsson, and the regional director Birgir Gudmundsson, client representative Jon Magnusson, and former directors Jon Rognvaldsson and Helgi Hallgrimsson. Also important to the gathering was Kristjan Moller, the former Transport Minister and a vital political supporter of the project.

A local choir sang to the gathering, including one number sung in Icelandic but to a traditional Czech folk tune,

Right: **A bracing, overcast morning before the official opening to explore the new tunnel**

Above: **Entertainment at the ceremony included a local choir…**

Above: **… and interpretative theatre**

internationally enjoyed and which was not lost on the Metrostav tunnellers who had joined the enlarged community and representatives of the joint venture partner, Hafell, that day. A group of performers of Reykjavik played out their interpretation of the mountain barriers being overcome and new friendships being won.

A religious blessing, then some official words and, finally, the ribbon in the national colours of blue, red and white was cut.

Community

Everyone was invited to the party, held in Olafsfjordur, which was only fair as Siglufjordur had been the venue of the contract signing in May 2006 and hosted a fete to celebrate work about to begin. Then, for the occasion, there had been baked a tunnel-like, 11m long stretch of confectionary – a cake – each metre representing a kilometre of tunnel. Following the official opening there was, in Olafsfjordur, cake again.

At the official party, held in the spacious community sports hall next to the town's open air hot baths, the contractors also commemorated the occasion with a few words. Hafell's general manager, Johann Gunnar Stefansson, spoke, as did Vaclav Soukup, a divisional director of Metrostav. Both were joined at the event by many engineers and managers from both firms, including Metrostav's project manager for Hedinsfjordur, Ermin Stehlik, Hafell's project manager Valgeir Bergmann, and some tunnel foremen and site staff. Also there were the client's supervision engineers from GeoTek, Bjorn A. Hardarson and Oddur Sigurdsson.

"In the last four years," Soukup said, "Metrostav Prague and its people participated in the Hedinsfjardargong project in the north of Iceland. More than 90 people from the Czech Republic have been regularly flown to Iceland to work on this project. On many occasions, they had to fight with hard conditions in the tunnels and there were moments when they doubted the possibility to finish the project, especially during the time when the large volume of cold water under high pressure leaked into the tunnel."

He continued: "Today the tunnels are open for public traffic and all difficulties are forgotten. I would like to thank all our partners, representatives of the client and supervisors, our suppliers and, of course, our joint venture partner Hafell for cooperation on this project."

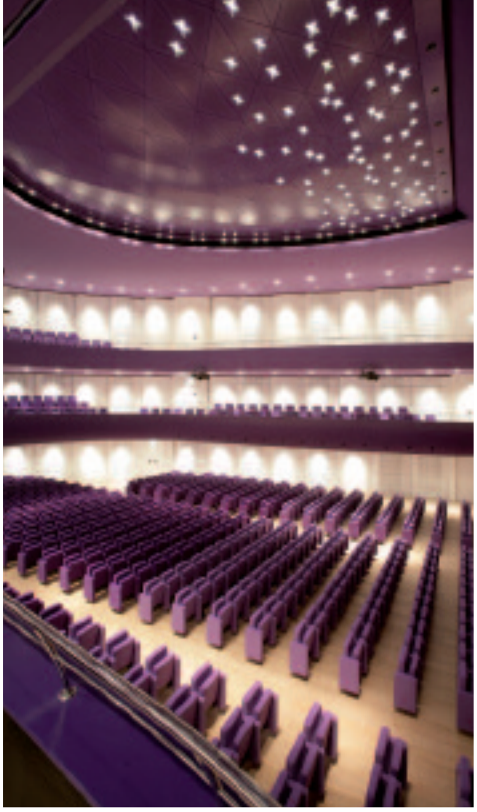
"Special thanks belong to our people working on the project and to the inhabitants of Siglufjordur and Olafsfjordur for their friendly relationship with our people."

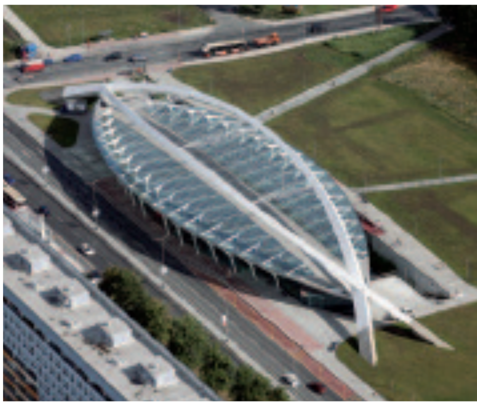
The network of friendships, contact and community is growing with the ease of all-year travel now possible for the communities, which transformed their municipal arrangements to establish a greater group – Fjallabyggd – as well as the extra visitors and more tourists already coming to the beautiful region.

Long and at times dangerous road trips round the coast and over mountain passes will no longer be journeys of necessity, but choice, in spring to autumn. Come winter, life and contacts will now continue thanks to the tunnels. In the north, life has changed.

Left: **Vegagerdin's director general Hreinn Haraldsson (left) and Metrostav's divisional director Vaclav Soukup (right) with the President of Iceland, Olafur Ragnar Grimsson**
Photo credit: Stepan Soukup

Below: **Tyra – man's best friend, in this case the friend of Metrostav's project manager, Ermin Stehlik**





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