Dagachhu Hydel Power Project: A Geological Challenge

Bird's eye view of the Dagachhu dam

Hydro Power is the backbone of the Bhutanese economy. Rugged mountains dominate the terrain and make the building of infrastructure difficult and expensive. However, the rapid altitude variations with swift flowing rivers have made Bhutan a natural haven for hydro power production. The decision by the Royal Government to exploit its water resources for production of electricity has changed the economic scenario for Bhutan. The close and friendly ties between Bhutan and India have provided the necessary political will and the market for Bhutan's power, as India has a huge power deficit.

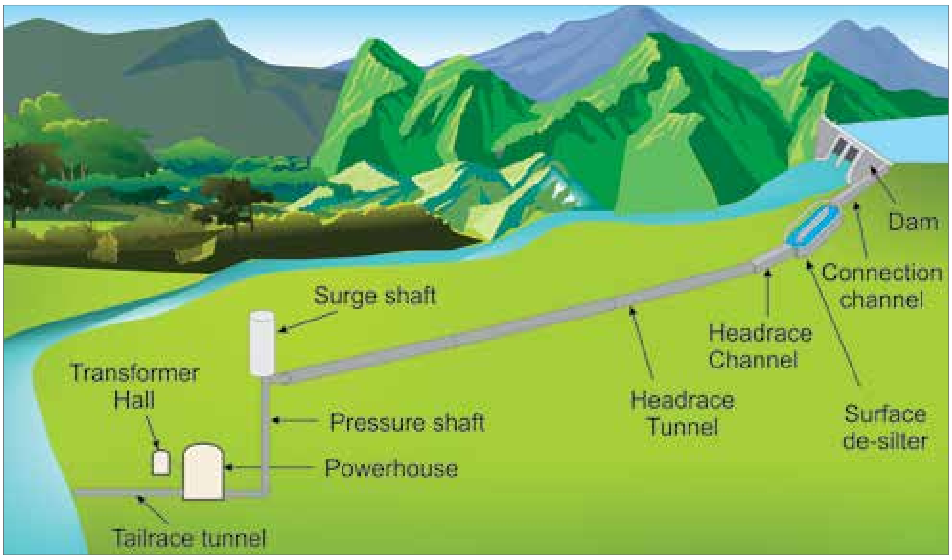
Bhutan's existing power production capacity is 6500MU of which around 1500MU is consumed internally and the rest is supplied to India. The Royal Government of Bhutan has committed to provide 10,000MW hydropower to India by 2020. Bhutan has also finalized a Rs 70,000 crore fund to be utilised in the targeted hydropower capacity augmentation project. A lion's share of this financial load is being shouldered by India. It is monitored by Druk Green Power Corporation (DGPC), the highest Hydropower authority of Bhutan.

Bhutan operates four major hydroelectric facilities, several small and mini hydroelectric generators, and a handful of further sites in development. The 1020MW Tala Hydel power project is the largest hydro electric power station built so far. The projects under construction include 1200MW Punatsangchhu project and 126MW Dagachhu project. The main civil works of the Dagachhu Hydroelectric Power Project on an EPC basis (engineering, procurement and construction) was awarded to HCC on July 20, 2009.

Description of Project:

The 126MW (2x63MW) Dagachhu Hydroelectric Project, located in the south-western part of Bhutan under Dagana Dzongkhag, is a run-of-the-river scheme being developed on the left bank of the river Dagachhu, located between 10.5km and 20.2km upstream of the confluence with the Punatsangchhu. The river stretch between the intake and tail race outlet is about 9.7km.

A concrete gravity dam of 95.874m length and 30.65m height with two spillway bays is built on Dagachhu river. From the dam site an artificial water way of about 9.129km has been built consisting of a 231m long connection channel, a surface desilter, a 285m long rectangular head race channel and a 7793m long horse shoe shaped head race tunnel. This is followed by a vertical pressure shaft of 3.4m diameter and 271m depth. An 18m diameter surge shaft has been built on top of the pressure shaft which is 47.8m high. The



Schematic representation of the Dagachhu hydel power project

pressure shaft is located below the Babithang village from where the water is channelled to the powerhouse located inside the rocky cliff. The powerhouse is equipped with two turbines with installed capacity of 63MW each. The tailrace is located near Churmuthang.

The elevation difference between the maximum water level at the intake and the turbine runner amounts to a gross head of 306m, which gives a gradient of 3.3%. The system is designed to convey a maximum flow of 50m^3/sec. The elevation of the project area and the catchment area ranges from 500m to almost 850m above mean sea level. The mean annual generation from the project is 515GWh and 90% dependable energy production is 360GWh.

Overcoming the mobilization challenges

The mobilization for the project began in October 2009. The project is located in the south west of Bhutan, in Dagana province which is one of the remotest in the country and is heavily forested. The equipment and material mobilisation were carried out through the border town of Phuentsholing which is around 420kms from the project location consisting of roads through hilly terrain and bridges with low carriage capacity. Transporting of heavy equipment was a major hindrance for mobilisation as the bridges were not adequate enough to carry the load at a single pass. Hence heavy equipment had to be dismantled at Phuentsholing yard, transported in parts and assembled at the project site.

There was no access to the power house location from the main road. Moreover, material could not be carried across the river as the temporary bridge was inadequate. As a result work at powerhouse site commenced around 58 days late. Further the terrain is steep and narrow and a large part of the project has more than a 70 percent slope and very limited flat land. The dam site is similarly steep with the slope gradients in many locations touching 100 percent. As a result landslides were frequent during mobilisation here.

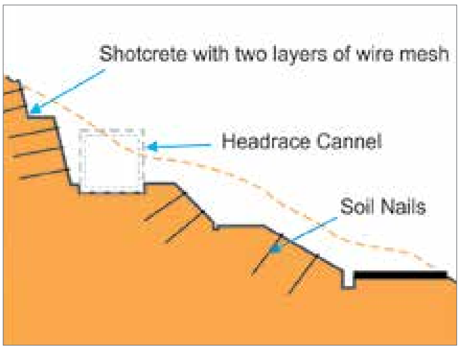
Poor Geological conditions

The geology over the project area consists mainly of metamorphic rocks of crystalline nature of the High Himalaya. Heavy rainfall had caused substantial chemical weathering of rocks and loose earth material were accumulated at the base of the hills due to avalanche, landslides and detritus moved by soil creep or frost action. Due to poor geological conditions, several alterations had to be made in the original design.

Dam design: The geology of dam foundation was not as per the tender specifications and excavations 3m below the specified foundation level were required. This change in depth of foundation had increased the quantity of concrete by approximately 20000 cubic meters. In the original design, the fish ladder was on the right bank of the dam. It had to be shifted to the left bank of the dam as the required gradient was not available on the right bank. Due to this alignment change, the length of the fish ladder was changed from 324m to 428m.

Headrace Channel: While starting the work on headrace channel, it was found that the ground strata was not adequate to hold the structure as there were several water courses beneath the surface and the land was marshy.

Our design consultant, SNC Lavalin's global geology expert from Canada was called to study the ground conditions and suggest a solution. Inclinometers, geotechnical equipment used to measure the underground movements and deformations, were deployed to study the ground conditions and extensive monitoring was done for a period of one year. The study revealed that the land was unstable and had significant underground movements. Accordingly, the alignment of the head race channel was pushed more towards the hills which increased its length by 25 meters.



Soil nails used for ground stabilisation


Retaining wall with soil nailing

In addition to this, the foundation of the head race channel required soil stabilization and construction of a retaining wall. Soil stabilization was achieved by additional shotcrete and a special anchoring called soil nailing. This anchoring was carried out simultaneously along with grouting so that no further movement occurs in future.

Headrace Tunnel: At the headrace tunnel, extreme geological conditions were encountered at two locations, one north bound 18.4m in length and the other at south bound 18.4m in length. The soil was loose, muddy with significant amount of water filtrate.

For tunnelling in the bad geological conditions, various support systems such as rock bolts, wire mesh with shotcrete, steel ribs, lattice girders and winches were used in varying quantities, classified as SC1, SC2, SC3, SC4 and SCL. SCL is support system for loose soil. However, situations encountered at these two locations was worse than expected. The tender specifications had not mentioned the type of soil strata, hence procedures to tackle the same were not in place.

The engineers came up with an economic solution of using pipe roofing. This methodology is time consuming and for excavating around 151 metres it took almost 18 months.

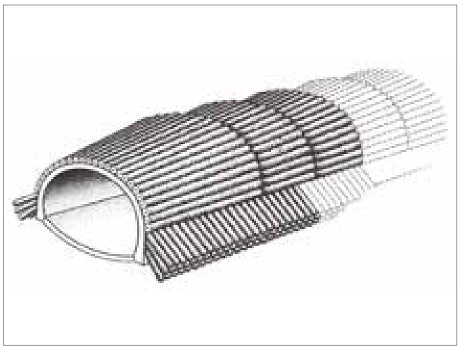
Powerhouse: The powerhouse excavation was a major challenge due to poor geological conditions. Excavation was done mainly in Mica Schist geology using NATM (New Austrian Tunnelling Methodology). For the first time in the Asian subcontinent, the powerhouse excavation was done by full face drilling and blasting method. The conventional method of power house crown or heading excavation is done by central gullet / side slashing method, where the central part is excavated by controlled blasting followed by side slashing. In full face blast the entire width of the crown is excavated in a single blast. DHPC engaged Bernard Engineers as the consultant for the full face drilling and blasting method deployed at Dagachhu. The crown or heading size in power house was 24.5m in width and 7m in height.

Surveying plays an important role in NATM. Face marking by the surveyor is the first activity involved in NATM. Before commencing the excavation, a survey is done by the team to check the geology, then drilling is done with a boomer to set the charge and immediately after the blast, a survey is done by the geologists at the face of the blast followed by face sealing shotcrete as a support measure before mucking. Then the support system is installed with rock bolts, wire mesh, shotcrete and lattice girder.

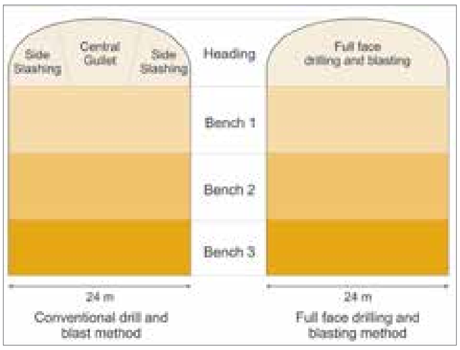
The full face drilling and blasting method is an 85 days cycle compared to the conventional method of 62 days. Hence excavation of crown or heading took 5 months during which 7000 cubic meters earth was excavated. However, this method has few advantages over the conventional method as the permanent support system is installed immediately after the blast making it operatively very safe. To speed up the remaining excavation, all benching excavation was done by the conventional method and it took just 5 months to excavate about 35000 cubic meters of earth.

After each blast, displacement of rock mass is monitored with borehole extensometer, optical targets and tape extensometer trigger values are specified for allowed deflections based on rock strata. In case, deformations are beyond these trigger values, then corrective actions such as additional rock bolting and shotcreting are taken immediately before proceeding with further excavation. Encardio-rite, an internationally renowned instrumentation consultant was engaged by HCC who worked with company's geologists to study and monitor the underground deformation during construction of the power house.

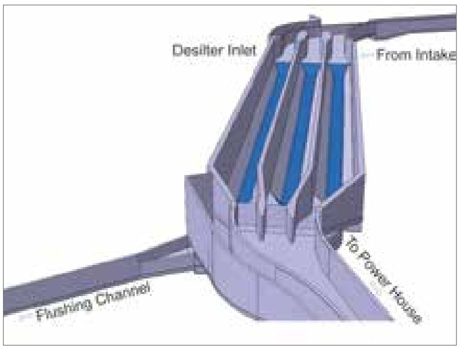
A 400mm thick shotcreting was done for excavation support in the powerhouse, with a total quantity accumulating to approximately



Pipe roofing used for excavation of headrace tunnel



Full face drilling and blasting vs conventional method

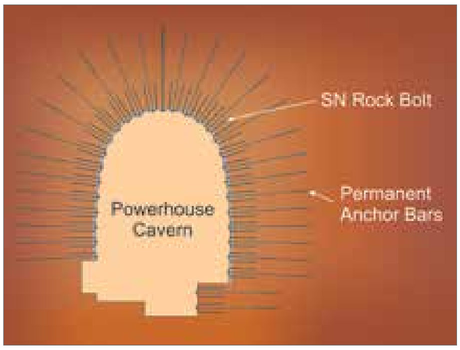


Surface desilter

Headrace tunnel lining work in progress

The powerhouse crown done by full face drill & blast

Powerhouse roof supported by lattice girder



Permanent anchor bars used to support structure

7900 cubic meters. Due to poor geology, the shotcrete grade was changed from M25 to M35 in powerhouse construction.

Permanent anchor bars were used for the first time in the Asian subcontinent for construction of the powerhouse. These permanent anchor bars were specially imported from South Africa. While installing these anchor bars, simultaneous grouting was done and with special hydraulic jacks these anchor bars were pulled to lock it in the position to a load of 425 Kilo Newton, making it active anchor bars. The anchor bars have a capacity to hold up to 1000 Kilo Newton load. There were around 500 anchor bars designed in the initial stage. However, due to adverse geological conditions they were increased to 1000 numbers.

Similarly, SN Rock Bolts envisaged in the initial stage were 1990 numbers. They were increased to 3000 numbers. Wire mesh used in the traditional tunnelling is made up of 5mm diameter wire. However, at the powerhouse 10mm thick wire mesh was used which increased the quantity from 25MT to 152MT. Wire Mesh was welded at the portal of the powerhouse and fixed inside to increase the pace of work. Lattice girder, which is used as a support system in the powerhouse for cladding and benching, was envisaged to be 1900 meters but was increased to 4000 meters.

Surge shaft with pressure shaft view at the bottom

Conventionally, Lattice girders are placed with a spacing of 3 meters between two girders. In Dagachhu powerhouse, due to adverse geology, they were placed at a distance of 1.5 meters to strengthen the structure.

Excavation of the powerhouse commenced in June 2011 and was completed in May 2012.

All civil works were completed and handed over to electro-mechanical contractors for installation of turbines and ancillary equipment on April 30, 2013.

Dimensions of Major Components:

Powerhouse Cavern	62.7 x 24.5 x 38m
Transformer Cavern	52.7 x 19.68 x 17.5 m
Installed Capacity	63MW x 2
No. of Units	2
Access Tunnel	275.25m
Emergency tunnel	285.29m
Tailrace Tunnel	686.42m
Tailrace Tunnel Size	4.8m

Tackling the challenges of cavity formation

The pressure shaft was to be executed by drilling a pilot hole 380mm in diameter and reaming of 4.10m by a raise boring machine. It was predicted in the geological report that there is mica schist at RD 41.90 to RD 56.4. Before undertaking the pilot hole drilling, the stabilization work of the mica schist rock was carried out by pressure grouting with cement slurry. After pilot hole drilling from top to bottom, excavation of the remaining 4.1m diameter was carried out by raise borer from the base of the pressure tunnel to the top. During excavation, it was observed that water was flowing at the bottom of the pressure shaft and material was continuously collapsing from the shaft side. The amount of water flow and the collapsed material increased during the first two days and around 700 cum of collapsed muck was removed from the bottom of the pressure shaft. To study the cause of material collapse, a video camera was lowered from the top of the pressure shaft.

It was observed that a cavity was formed between RD 32 to RD 56, due to a collapse in the sides of the shaft and the cavity formation was advancing upward. This posed a serious threat towards a total collapse of the pressure shaft and surge tank.

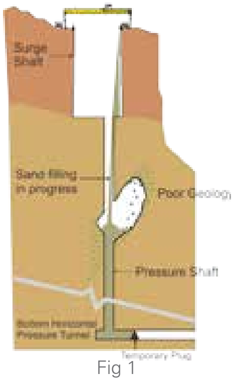


Fig 1

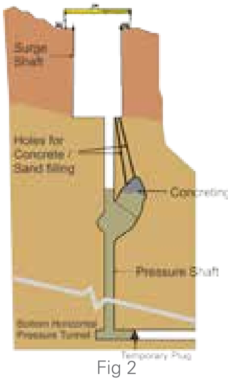


Fig 2

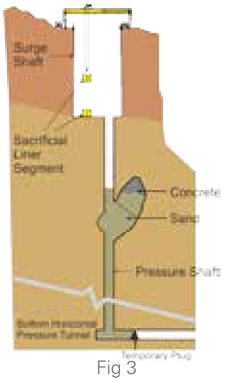


Fig 3

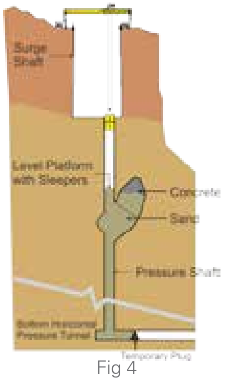


Fig 4

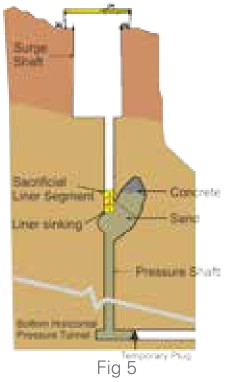


Fig 5

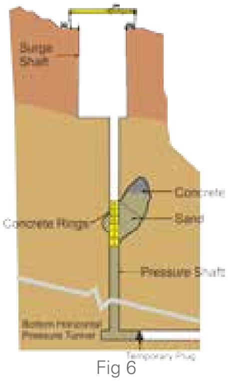


Fig 6

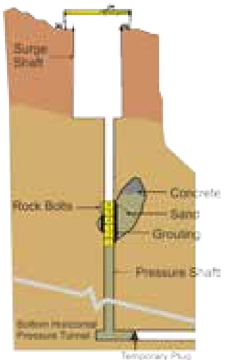


Fig 7

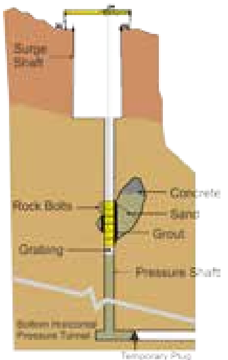


Fig 8

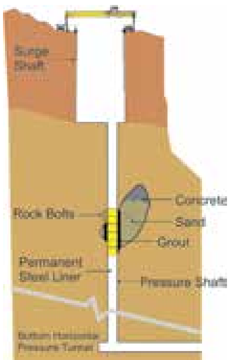


Fig 9

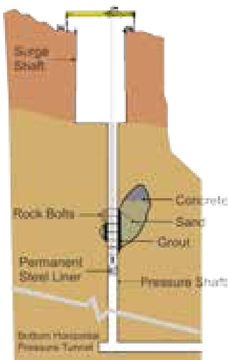


Fig 10

Innovative Solution: To restrict any further collapse, a temporary plug was initially constructed at a lower horizontal pressure tunnel and the pressure shaft was filled using sandy material up to RD 34. After filling the pressure shaft up to RD 34, manual inspection was carried out and it was observed that the cavity had advanced in the northern direction at one side of the borehole.

Further sand filling was done up to RD 30 in order to fill the cavity at the northern side of the borehole. 23 holes were drilled around the pressure shaft from the bottom of the surge tank of which around 15 holes punctured the cavity. Through these holes sand filling was carried out followed by concrete filling and grouting.

Alternate options were discussed for stabilising the collapsed side of the pressure shaft. The proposal for a sacrificial liner sinking was finalized based on the principle of well sinking in sandy strata by using a concrete counter weight and manual excavation at the cutting shore.

Current status:

Despite the adverse geological challenges, the HCC team has worked relentlessly to complete the project. Among various components, the desilter, surge shaft, powerhouse cavern, transformer cavern is completed in all respect. Around 99 per cent of the concreting work is completed on the dam, 97 per cent work on pressure shaft and only 4.3km lining work of the headrace tunnel is balance. All the civil works are expected to be completed by end of first quarter of the year 2014.

Equipment used

Equipment	Make
Wet Shotcrete Machine with Robo arm	Normet Spraymec
Tunnel Loading Machine	Terex ITC
Telehandler with Rib Erector Maniscopic	Manitou
Injection grout pump	Atlas Copco
Drilling Rig	EGT
Electric Compressor	Atlas Copco
Pneumatic Crawler Drill	Atlas Copco
2 Boom Rocket Boomer	Atlas Copco

DID YOU KNOW ?

Fish Ladder

Most fish species make only two really significant journeys in their lives. The first is shortly after birth, when fish move away from their spawning grounds, and the second occurs when the fish return to the spawning area to breed and die. When the world was undeveloped, the only threats to these journeys might have been bigger predators and fishermen, but now, fish face huge barriers and obstructions in the form of dams. If they can't get back to the spawning grounds, then fish populations dramatically decrease.

That's where fish ladders come in. Fish ladders provide a detour route for migrating fish so that they can get over or around a dam that's blocking the way. That sounds easy enough, but when you try to visualize such a contraption, you may have funny images in your head. How could a fish make it up the rungs of a ladder? Try picturing this instead: a series of ascending pools that are reached not by climbing rungs, but by swimming against a stream of water. The fish leap through the cascade of rushing water, rest in the pool and then repeat the process until they're beyond the dam.

A lot of work goes into designing a fish ladder. The height and grade between the pools, the number of pools, the size of the pools and water flow are but a few of the factors that have to be considered. And fish ladders aren't one-size-fits-all -- each has to be tailored for the type of fish that will be using it. For example, trout and salmon have the talent for powerful bursts of swimming speeds, which means they can swim against stronger currents of water that other species can't. Yet you can't make the water flow too weak, as a meagre trickle won't attract the fish to the passage entrance.

There are, however, some basic designs for fish ladders that can serve as a blueprint:

- A pool-weir fishway usually has a hole at the bottom of each pool level so that fish can jump up from level to level.
- Fish using a vertical slot fishway are guided upstream by a narrow passage that winds around the barrier; the water flow is constant and the fish don't have to jump as much.
- Denil fishways are like choose-your-own-adventure books because baffles create rapids of different speeds so that many fish species can pass.
- Steeppass fishways work similarly to the Denil style, in that there are many different water velocities. They're usually narrower, though.
- If you want the fishway to blend in with its surroundings, try a natural bypass by using natural materials to recreate a stream.

Fish ladders aren't foolproof. Sometimes fish have trouble finding the entrance, or long fish ladders exhaust the fish from reaching top. Additionally, while fish ladders are designed to get the fish back upstream to the spawning grounds, there must be protection for the young fish going downstream without which the young fish could get caught in a turbine.