FEATURE ARTICLE

Staging area and Bentonite treatment plant at the right abutment upstream of the cut-off wall *(© BAUER)*

# Cut-off Wall at Tight Site in the Himalayas

The Punatsangchhu-1 hydro-electric project (PHEP) is one of 10 hydropower plants being built as part of extensive infrastructure development in Bhutan, a landlocked state bordered by India and China. The 1,200 megawatt project will supply the nation with electricity, and some will be sold to nearby India. The dam is notable because of the steep constrained site and the difficulty of construction; in spite of which the dam was built on time and on budget. State-of-the-art hydro cutters were a major factor in this successful project.

The dam design minimizes effects to the environment. Its height was kept to a minimum in the valley and is only 150 m (492 ft) wide, due to twin tunnels in the mountain range on the left and the location of the power station turbines downstream at the end of the tunnels. At its deepest point, the wall depth is 93 m (305 ft). A river at the site was rerouted through a further tunnel and two additional cofferdams were installed upstream and downstream of the main dam. The foundation is embedded in rock, preventing currents from going below.

The Punatsangchhu Hydro Electric Project Authority of Bhutan is coordinating the entire project and will also be responsible for the subsequent Punatsangchhu-2 hydro electric project further downstream. Larsen & Toubro Ltd. (L&T), Chennai, India, was the contractor for the main dam for PHEP-1. In 2011, Bauer Spezialtiefbau GmbH received the contract for a concrete cut-off wall for the cofferdam upstream.

## Geology

The Punatsangchhu Valley, east of the project, has no run-off hill scree in the area of the steep left shore, which has an angle of up to 80° towards the existing river bed. The shore on the right side has more moderate slopes and is heavily eroded. There are also large scale colluvial slope overburdens, as well as river sediments. The soil material is heterogeneous. The existing rock in the valley bottom also varies both in its course and its strength, i.e., highly weathered gneiss next to fresh gneiss with individual quartzite deposits.

The soil layers at the cut-off wall are sandy and gravelly, and contain water in some areas. With declining depth, there are cohesive soils and boulders that reach the size of a house. The strength of sound rock and the valley soil are between 50 and 150 MPa (7,250 and 21,750 psi). Isolated wood was found at great depths. From the work platform at a level of 1.17 m (3.85 ft) above sea level, the valley bottom reaches a depth of 90 m (295 ft). The river level – in general at 1.17 m (3.85 ft) above sea level – does not correspond to the second ground water level (1.15 m/3.77 ft) above sea level, which is fed by slope water and subsurface inflow.

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By installing a reinforced concrete slab on soil that was compaction-grouted at a depth of 20 m (66 ft), settlements of the heavy dam structure were prevented prior to the cofferdam construction. Grouting was done by another subcontractor of L&T. For safety reasons, the upper edge of the cofferdam was designed at a level to be 2 m (6.6 ft) above the highest possible flood level. The water level after a possible flashflood (arising from a sudden glacial lake break) was also considered for the final dam height.

## Steps to Successful Completion

On a reinforced concrete slab 150 m (492 ft) away from the work platform, Bauer built a bentonite mixing plant and a regeneration plant for two cutter units and a grab. Steel containers and two circular in-situ concrete basins for fresh bentonite, concreting bentonite and working bentonite, were provided for stock-keeping. The contractor also ensured constant power supply by providing generators. Bentonite slurry was produced by two mixers and recycled by two desanding units for the two cutters. A third desanding unit served as a replacement and also cleaned the slurry, which was pumped back during concreting or grabbing.

A platform for the cutters, grabs and assistance cranes consisted of broken stones from the tunnel works. An L-shaped concrete guide wall enabled proper measuring and installation of the cut-off wall panels. Another independent grouting work was on the working platform of the cofferdam, consisting of the mixing plant, pumping containers and storage containers for the slurry. Bauer also built a separate workshop for welding and for storage close to the bentonite treatment plant to ensure prompt supply for the ongoing works.

The pre-treatment was soil grouting that formed a matrix in the alluvial soils. This grouting stabilized soil, cobbles and boulders and filled possible cavities. Larger boulders were fixed in the soil structure by tubes-à-manchette to prevent them from falling into the slurry filled trench during the diaphragm wall works.

Two weeks before the start of the concrete cut-off wall work, the contractor drilled at distances of 2 m (6.6 ft) on the upstream and downstream sides of the

## Foundation Engineering

India's Water and Power Consultancy Services planned and controls the project. The challenges for site preparation for the main contractor L&T were diverse: building roads, providing water and power supply, providing accommodation and food for up to 5,000 workers and preparing access roads for heavy equipment.

The engineers had to coordinate the tunnel construction, and the installation of cofferdams as well as the cable car for material supply. Earth work and the special foundation work at the upper cofferdam also had to be overseen.

The original concept for seepage protection was to seal the dam using high pressure injection. Mainly for economic reasons, but also due to schedule concerns, Bauer, with the client and the owner, opted for a solution with a cutter-excavated diaphragm/cut-off wall to ensure water tightness. To prevent boulders sliding into the open trench, injections were made along the cut-off wall installation.

**The concrete cut-off wall with two BAUER Trench Cutters, one BAUER Hydraulic Grab and support cranes** *(© BAUER)* planned cut-off wall. The drilling was done in turns, alternating gravity grouted or pressure grouted via pre-installed tubes-à-manchette. The W/C-ratio of the slurry was adjusted to meet the different geological characteristics and the varying cement properties. The injection filling used a very heavy (low-moisture) slurry, the tube-à-manchette grouting was optimized with up to three slurry types of different consistency.

The maximum drilling depth was reached at 95 m (312 ft), using double rotary heads with percussion (133 mm/78 mm or 5.2 in/3 in). To eliminate unavoidable deviations, the initial drilling points were located with sufficient distance to the future diaphragm wall. This was done according to the expected depth of the rock horizon to prevent steel tubes-à-manchette protruding into the face of the cut-off wall. In 2011, prior to the actual works, Bauer conducted concrete tests to ensure suitable fresh and hardened plastic concrete. In this case “suitable” meant: filling with the tremie method, percussion resistant, fully workable within at least four to six hours, elastic, water tight and designed for limited strength. The concrete mix design for plastic concrete met the following criteria: permeability $10^{-8}$ m/s ($3.048^{-8}$ $ft \cdot s^{-1}$), E-module of 1,000 MPa (145 ksi) and uniaxial compression strength between 1.5 to 2.5 MPa (218 to 363 psi). After a series of different mixtures the most suitable mix was found, using locally available material.

Due to the cofferdam body, built to a defined level prior to installing the cut-off wall, a clay core of up to 12 m (40 ft) in depth had to be excavated by a grab to minimize contamination of the bentonite through fines. Immediately afterwards, workers excavated the trench to its final depth. The performance varied depending on existing boulders, and reached on average 25 m² (270 ft²) per 24 hours and rig. The panels overlapped at 30 cm (11.8 in) for wall depths of up to 50 m (164 ft) and at 40 cm (1.3 ft) for wall depths of up to 90 m (295 ft). The allowable verticality tolerance in the wall axis was a maximum of 0.5 %.

Bhutan has strict import regulations for chemical substances. Therefore, additives to regulate the pH-value and the viscosity of the bentonite, due to the overcut of primary by secondary panels, could not be used in a standard required quantity. So fresher bentonite was added, which could only be managed by very big earthen basins for bentonite waste of more than 5,000 m³ (6,540 yd³) and regular slurry disposal was done by concrete mixer vehicles.


**BAUER MC 128 and Trench Cutter BC 40** *(© BAUER)*

Concreting was done with tremie pipes having a diameter of 254 mm (10 in). The concrete mixer and the mixing plant were designed for loads of 6 m³ (7.8 yd³) each, so that a necessary performance of 60 m³/hour (80 yd³) could be exceeded if up to 10 mixers were deployed. The concreting bentonite displaced by the concrete was recovered by big submersible pumps, except in the upper 5 m (16 ft), and restocked into the loop. As the soil concrete hardened according to plan, it was not necessary to use stop end plates to protect the neighboring panel.

The additional consumption was limited to 20% in extreme locations. Self-imposed strict intervals for equipment maintenance contributed to minimize standstill times.

## Verification

The contractor installed the concrete cut-off wall within the specified tolerances, which were tested during execution with B-Tronic, an electronic system preinstalled in the rig that assists the machine operator. After reaching the final depth, the working slurry was exchanged by a concreting slurry that met the slurry specification to be reached prior to concreting. The actual trench deviation was measured and documented by KODEN, the ultrasonic quality control tool.

This KODEN data was included in an AutoCAD 3-D model. As the diaphragm wall center points were measured into a global 3-D-system, the complete cut-off wall could be displayed in a 3-D model. Thus, the continuity data of the diaphragm wall could be provided both for the x-axis and the y-axis. The designed embedment of 60 cm (24 in) ensured proper sealing in the bedrock. A geologist assigned by the client provided his expertise.

Moreover, the contractor conducted extensive tests with the fresh and hardened concrete. Samples were taken from the fresh concrete during mixing and tested on fresh concrete suitability and on hardened cubes and cylinder for strength and permeability. For the complex tests on the E-module, to determine the kf-value and for the tri-axial tests, the contractor sent the samples to India, where they were tested in the client's laboratory. In all cases, the necessary values were achieved. Before concreting, the workability was tested for any tendency to segregation or bleeding. To be on the safe side, further samples were stored.

## Challenges and Solutions

**Mobilization:** Admissible transport weights, available widths and heights of Bhutan's roads made it necessary to dismantle the major rigs to their smallest components, thus a weight of 40 tonnes (44 tons) was not exceeded. The containers are limited to a length of 6 m (20 ft). No equipment could exceed a height of 4.5 m (14.8 ft).

**Grouting:** The quality (thread and rubber manchettes) of the 5 cm (2 in) steel tubes-à-manchette was decisive for the tightness and assembly of the packers. The contractors mobilized high-quality tubes. Drilling deviations of more than 2.0% resulted in a new drilling location to prevent the tubes-à-manchette from protruding into the cut-off wall area. Creeping injection material required large drill distances of at least 20 m (65 ft) drill location to location.

**Bentonite:** The lack of sodium-bicarbonate resulted in high bentonite consumption. This necessitated mixing fresh bentonite in a short period of time. By cutting the concrete of the primary panels during excavation for the secondary panels, the working bentonite quality was at the limit of the specified range. The working bentonite was exchanged with bentonite of specified parameters to ensure the necessary quality as the bentonite can only be marginally improved by adding water or a limited volume of fresh bentonite.

Disposing the waste bentonite was a vast logistical issue, as was supplying spare parts. Due to the long journey from abroad, possible shortages and consumption had to be calculated about two months in advance. Subterranean waterways were another challenge. Currents washed off the injection material, and at various locations workers had to repeat the injections several times to ensure a stable trench.

**BAUER MC 128 Base machine with HDS and Trench Cutter BC 40 rigged up for rock cutting to depths of more than 100 m (328 ft)** *(© BAUER)*

## Schedule to Completion

In the upper cofferdam of the Punatsangchhu-1 HEP, 55 panels with a nominal thickness of 1.2 m (3.9 ft) on a dam length of 135 m (443 ft), overlapping with 30 cm (11.8 in) and/or 40 cm (15.8 in) and with a maximum depth of 93.5 m (307 ft) were completed. Small diameter drillings and two types of grouting were done: gravity grouting and tube-à-manchette grouting, whose maximum drilling depth was 96 m (315 ft).

At peak times, up to 30 skilled expat employees were on site in day and night shifts in addition to the 60 local helpers to work and to ensure quality standards.

Overall, the contractor installed a 7.067 m² (76,069 ft²) cut-off wall (without overlapping areas). The actual work started mid-April 2012 and was completed by mid-November 2012. Despite surplus quantities of 30% due to a bigger wall depth compared to the contract and a construction schedule that lasted theoretically 30% longer, Bauer was able to finish earlier than the specified total construction time predicted for the diaphragm/cut-off wall.