DEEP FOUNDATIONS INSTITUTE

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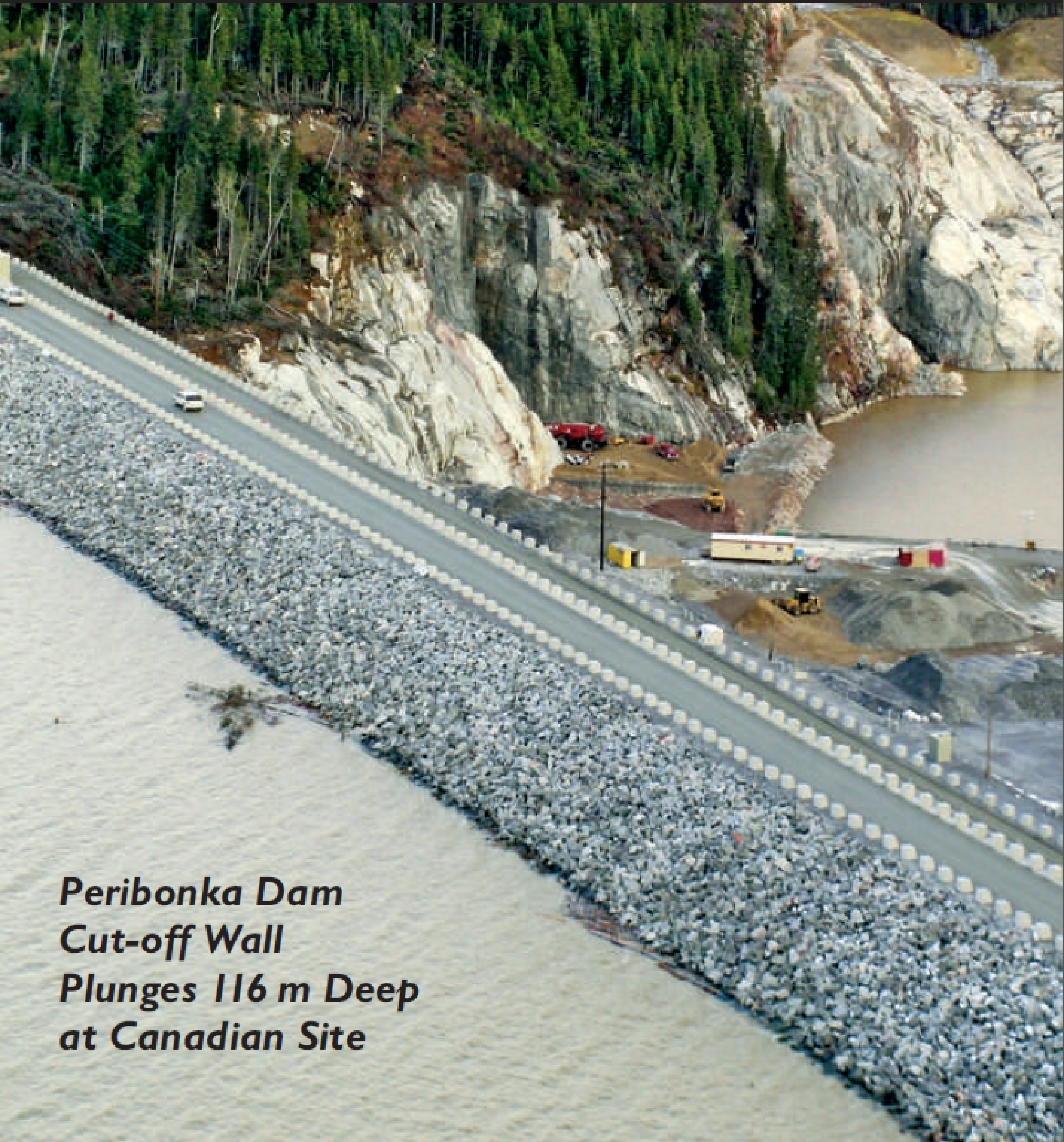
Spring 2010

The Magazine of the Deep Foundations Institute



Peribonka Dam Cut-off Wall Plunges 116 m Deep at Canadian Site


Peribonka Dam River

Challenging Cut-Off Wall at Peribonka Dam

Owner Hydro-Québec and designer SNC-Lavalin faced problems with water seepage at the 80-m-high dam along the Peribonka River in Québec, Canada. The solution was a plastic cut-off wall in unusually complex ground conditions through deep alluvial deposits that form the dam foundation. The wall, now successfully completed, is exceptionally deep, about 116 m at one point. The bedrock, where it was keyed, underlies coarse highly permeable alluvial deposits, and formed a buried valley with steeply sloped flanks, creating further difficulties.

Contractor Bauer Spezialtiefbau GmbH, based in Germany, constructed the cut-off wall through its Canadian subsidiary, **Bauer Foundations**, Canada, Inc. Bauer incorporated a variety of geotechnical construction techniques and methods that were stretched to new limits. Constructing the plastic concrete cut-off wall with a trench cutter was a pioneering accomplishment in the complex ground conditions.

Site Investigation

The soil investigation performed in 2003 showed an extremely deep 60-m-wide valley in the bedrock underlying the riverbed alluvium. The canyon-like fold, a glacial gully, was filled with cobbles and boulders, with dimensions of up to 1 m within a sandy matrix with zones of high permeability. There were further challenges, such as the almost vertical flanks and overhangs of the bedrock, and concentrated boulder zones. In addition, the granite and anorthosite at the site had measured strengths in the range of 120 to 180 MPa, and occasionally in excess of 200 MPa.

The alluvial layers encountered and the open talus structure further jeopardized

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the open cut-off trenches. The investigators expected sudden losses of the supporting fluid that would destabilize the boulders above the cutter frame. Furthermore, in-situ stability of boulders and large cobbles had to be ensured.

To mitigate the risk of instability, Bauer Foundations, Canada, grouted the alluvial zones in the gully section, creating a section 10 m wide with a depth of 120 m along the dam axis. The grouted soil body had the advantage of preventing erosion. Besides the cut-off wall and the alluvium grouting, some other challenging geotechnical measures were:

- Intensive drilling in the glacial gully section to identify the contour of the bedrock, as well as the location of large boulders in the dam axis
- Bedrock consolidation grouting
- Soil improvement by vibro compaction of the alluvium layer and the dam base to mitigate the extent of settlements and risks of liquefaction due to seismic activity
- Installing a ground water lowering system during construction to control potential rising river water levels

Grouting Procedures

Bauer used "tubes à manchette" to grout the alluvia within the glacial gully. The main concern here was the risk of a limited penetration range of the grout and the grout intake quantities.

Locally limited zones seemed to be suitable for permeation grouting with conventional cements. However, in some of the alluvia, the portion of the middle size sand fraction (with D<1 mm) exceeded 15%. In these areas, the soil could prove unsuitable for permeation grouting. The major risks regarding the stability of open trenches, and hence the safety of the cutter, were related to those zones. Because of these circumstances, Bauer modified the refusal criteria for grouting works, allowing limited hydro-fracturing of the soil to open additional paths towards the talus pockets.

Bauer performed limited gravity grouting, where the boreholes were filled with stable but low viscosity mix to allow the grout penetration through a wide front over the complete borehole. In general, the classical grouting sequence with primary and secondary tubes was applied.

The strict requirements for the quality of the work and the tight work schedule necessitated the use of automatically controlled grouting units. Three-dimensional plotting of the grout distribution, based on inclinometric measurements and systematic recording of all parameters, was an effective real-time support for the work.

General site view

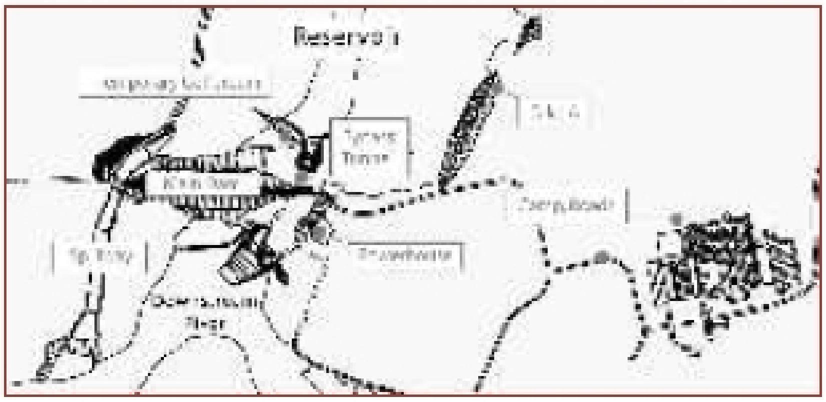
Cut-off wall in progress

Plastic Concrete Cut-off Wall

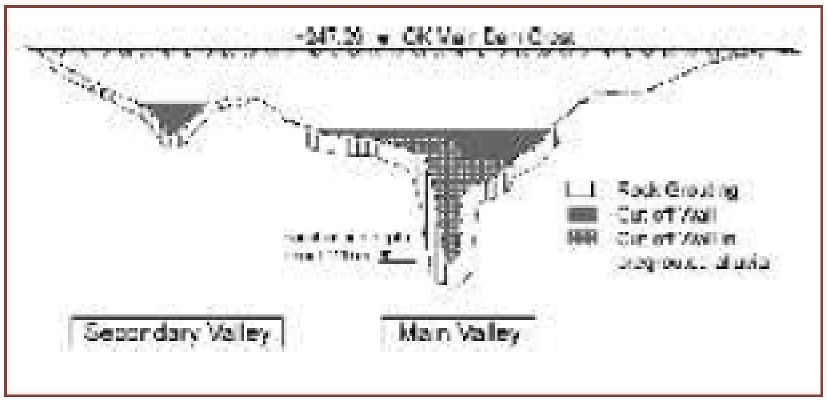
Cut-off walls were constructed in several areas of the dam. Here we considered only the exceptionally deep wall in the glacial gully of the main river valley. This wall's width ranged from 1,500 mm to 1,200 mm, with 116 m maximum depth, with a total area 12,000m2.

The trench excavation took place in zones previously treated by cement grout. We took special measures to maintain the workability of the supporting fluid. This was due to several factors: the relatively high water/cement ratios of the grout; the low temperatures of the ground; the comparatively short time period between the finishing of grouting works and the excavation of the panels; and the large volumes of panel joint overcuts. The viscosity rapidly increased to very high levels, due to the sensitivity of the bentonite to cement contamination. This increase exacerbated the need to control the rheological properties of the supporting fluid to facilitate slurry circulation between the cutter pump at the bottom of the deep trenches and the desanding unit.

Technical solutions such as the dosing mechanism integrated into the cutter frame enabled Bauer to introduce the additives at the right location in the vicinity of the cutter pump, i.e., at the deepest level of the trench under the excavation. At the same time they closely monitored the degree of slurry liquefaction to maintain sufficient supporting effect.



Site plan view



Dam longitudinal section

Bauer had to maintain immense quantities of supporting fluid reserves in this operation. The storage basins for the fresh excavation and concreting slurry were covered for protection during the cold months. The bentonite in basins was continuously agitated by pumps and high-speed impellers. In addition, heating elements had to be installed to prevent the slurry mixed into the plastic from freezing.

One of the most important mechanical properties of plastic concrete is its ability to follow the deformations of the dam and the soil layers underneath its base caused by the rising water head when the reservoir is filled. The designer always wishes to have a low modulus of elasticity in the plastic concrete. Usually the required compressive strength of the hardened plastic concrete does not exceed the few bars required for sufficient stability against mechanical erosion.

Therefore, it is usually not very difficult to find a reasonable compromise between both parameters (strength and E-modulus), despite the comparatively narrow correlation between these two parameters. However, due to the dimensions of the Peribonka Dam, the cut-off wall underneath was exposed to considerable stresses. These were due to the weight of the dam and the height of the acting water head; both required higher compressive strengths. That is why this project called for extreme fine tuning of the clayey components, and the water/cement ratios of the mixes had to hit the narrow envelope of the correlation range.

The required high plasticity restricted the aggregate portion in the plastic concrete mix. The high fluid phase content of the mix, in addition to the required flowability, resulted in adjustments to limit the bleeding typical for such mixes placed under the considerable hydrostatic pressures associated with deep panels.

Based on the originally assumed rock profile in the glacial gully, we expected that the wall would reach a depth of more than 120 m at its deepest point, and constructed a cutter prototype especially for the project. Two more standard cutters were also mobilized.

The wall depth necessitated additional measures for the verticality control to ascertain interlocking of the panels. Considering the complicated soil conditions, Bauer adapted the cutter direction control plates to allow longer stroke lengths, thus increasing the correction efficiency.

Besides standard online monitoring and logging systems for parameters such as the deviation in both axes, depth, penetration progress, torque of each wheel and retention force acting at the hook, the largest cutter was further equipped with a gyroscope that monitored eventual rotations in the panel excavation.

Advanced Cutter Technology

As a technical solution, within easier reach of the currently available technology, the cut-off wall was originally designed with a limited rock keying of the individual panels, over less than a half of their length, to facilitate its execution in the gully section against very steep rock slopes. The resulting "windows" underneath the non-embedded panel base were to be subsequently treated by cement or chemical grouting, depending on the groutability of the soils found.

Bauer proposed an alternative which, making use of advanced cutter technology, allowed for a full embedment of the panels into the rock to avoid the risks associated with such deep "windows," though this option would bring the project into pioneering territory.

To ascertain a better compliance with the requirements regarding the overcut joints of the adjacent panels, Bauer developed a specific methodology. By starting panel construction at the deepest point of the gully we could utilize the completed panels successively as abutments for the following panels. This allowed better control of the cutter frame verticality during cutting into the

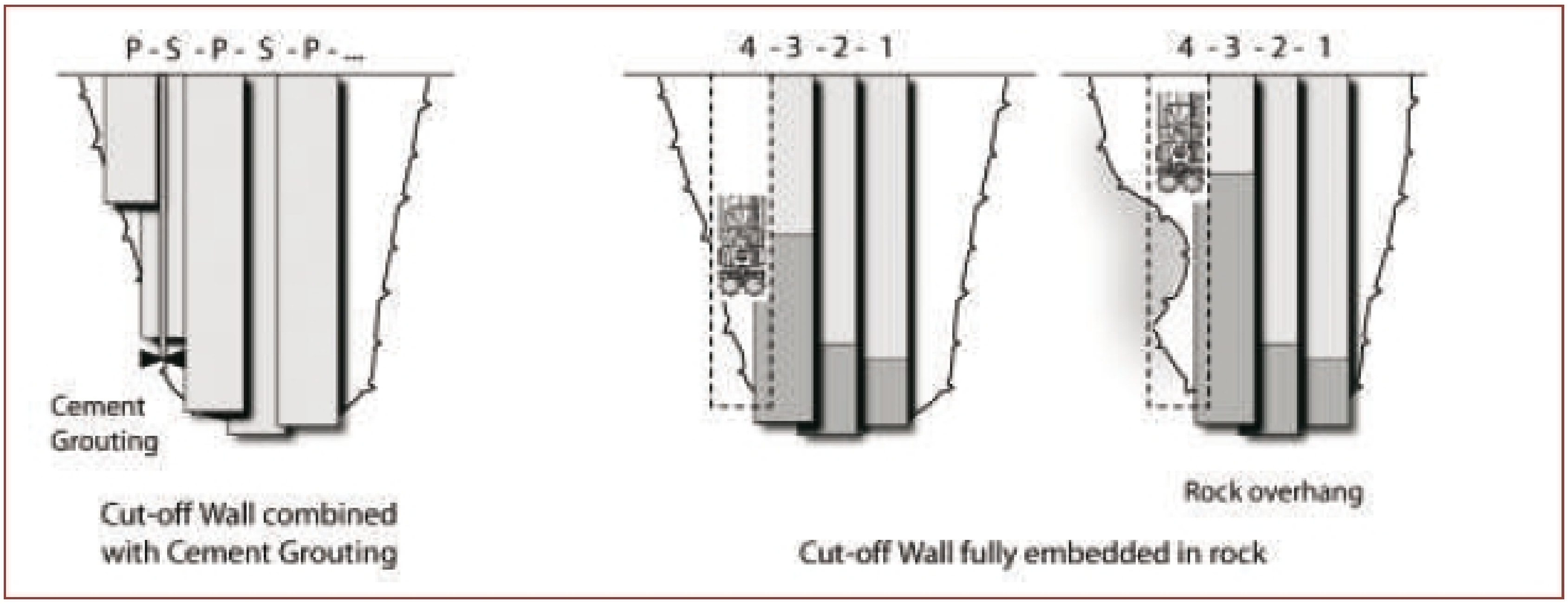
Cut-off wall in progress

steep rock surface. Since the plastic concrete, with its specified 28 days compressive strength, could not serve as abutment with sufficient strength to counteract the rock influence on the opposite side of the cutter frame, it was replaced at greater depths by structural concrete with strengths in the range of 30 MPa.

Such a sacrifice of the concrete plasticity could be afforded at greater depths, since the cut-off wall there was not exposed anymore to deformations. The methodology was verified on trial trenches at a location outside the dam axis with similar rock surface slopes before it was put into practice.

The wall paneling was designed with the overlap between the panels increased to 60 cm in critical zones instead of 30 cm. Also, in such complicated areas as zones with significant multi-axial slope inclinations of the rock and sizable boulders, some of the panels were rotated to a position perpendicular to the dam axis. This rotation could accommodate larger deviations in the alignment normal to the main wall direction.

Beside the preventive design and quality control measures described here, real-time adjustment of the adjacent trenching was systematically implemented, based on careful monitoring.



Alternative rock key solution

Panel Verticality

The special concerns of this project included the high risk of joint defects between adjacent panels. This was due to the extreme ground conditions and depth, and the quality of panel embedment in rock.

An absolute prerequisite for wall integrity was strict control of panel verticality. This was especially important in the case of deep cut-off panels, where the smallest deviations lead to reduced overlap and in the worst case, to gaps between adjacent panels. The variation of the wall thickness between 1.2 and 1.5 m was designed on the basis of the depth of the relevant dam section. Specifications called for a minimum overlap of 20 cm between adjacent panels and a minimum wall thickness of 70 cm to achieve the required integrity of the wall. Even such a marginal deviation from the verticality as 0.5% would have exceeded the limits required to meet the specified criteria. To increase the safety of execution and to take into account the accumulation of unfavorable conditions, the nominal panel overlap in the most critical areas of the wall was increased to 60 cm.

The deviation and torsion of the cutter frame were monitored by real-time measurements conducted by the two inclinometers and the gyroscope installed on the cutter frame, enabling the cutter operator to correct any deviations during the excavation. Finally, the alignment of the trench was controlled by ultrasonic cross-hole measurements.

The overlap section of each panel was carefully analyzed based on the comprehensive joint record to consider the necessary measures needed before commencing with the excavation of the adjacent panel.

Several control points were established to verify the specified embedment of the panel base into the rock. We also used the results of the rock surface detection obtained during the drilling for the preliminary panels, and the additional interpolation between the rock surfaces encountered in the primary panels to verify the rock embedment of the secondary panels. The oil pressure of the gear box for both cutter wheels was also monitored. Finally, samples of the excavated material separated at the coarse sieve of the desanding unit were systematically inspected and sampled to confirm the rock key quality.

Conclusion

Bauer completed the plastic concrete cut-off wall in October 2006. The civil works were completed in October 2007 and the first generator was put into service in December 2007, to the full satisfaction of the owners. Piezometric monitoring continues to ascertain the behavior of the cut-off wall.

The plastic cut-off wall at Peribonka demonstrates that it is now possible to install highly reliable plastic concrete barriers against water seepage in extremely challenging geotechnical conditions well beyond the reach of other currently available techniques.