Optimization of works on an existing dam serving a medium sized hydro plant: Challenges and opportunities

Matteo Rebuschi
Frosio Next S.r.l.
Via Corfù, 71
25124 Brescia (BS)
Italy

Eliseo Marchesi
Frosio Next S.r.l.
Via Corfù, 71
25124 Brescia (BS)
Italy

Luigi L. Papetti
Frosio Next S.r.l.
Via Corfù, 71
25124 Brescia (BS)
Italy

Introduction

Dams, in general, are subject to periodic review of technical rules for the operation - such as the recalculation of the thousand-year return period discharge (used as reference for the dam's hydraulic safety) - and are subject o site controls, for example structural condition assessment. The works at the Cassiglio dam, managed by the concessionaire Italgen S.p.a., discussed in this paper were carried out because the sliding stability analysis was no longer verified according to recent new rules adopted at a national level. To make the dam compliant to the new rules a weighting of the dam was designed and implemented by casting massive concrete at the upstream face of the existing dam. During this works, to optimize the downtime of the HPP, two additional works were completed: the removal of the sediments in the reservoir and the complete revamping of the plant's hydroelectric components.

The works at the dam required 9 months, the revamping of the HPP lasted 5 months and the removal of the sediments was completed in 8 months.

The HPP is located in an Alpine valley, the Brembo one; the dam is a 20-meter-high concrete gravity structure, originally built with 5.300 m^3 of concrete. The spillway had a discharge capacity 100 m^3/s, while the bottom outlet can release 34 m^3/s; the result of the recalculation of the thousand-year return period discharge was 170 m^3/s. Demolishing the piers, the Creager-Scimemi profile and the crest was necessary for the spillway upgrade. It was rebuilt with a single pier and a higher dam crest. In order to dissipate the energy of the updated project discharge, it was necessary to have a longer stilling basin. The existing one was therefore demolished and rebuilt with a longer extension and higher lateral walls.

In this paper, the full details of all the works carried out will be described, highlighting the challenges faced, the problems encountered and solved, and the lessons learned. There will be a special focus on the selection and on-site controls of the materials, the operational difficulties resulting from the simultaneous weighting at the dam and removal of the sediment, and the tightness of the time schedule. Finally, some general conclusions useful for similar situations will be drawn.

1 Description of the HPP and the dam

1.1 The Cassiglio dam

The Cassiglio Dam, built in the early 1950s, is a concrete gravity dam with a straight planimetric axis, founded on the underlying limestone bedrock.

The dam is 20.5 m high, and the cross-section has a triangular profile, with a uniform upstream inclination. In contrast, the downstream face consists of a vertical section in the upper part and an inclined section down to the toe.

The entire central part of the dam features a spillway crest, which serves as the surface spillway and has an overall width of 21 m out of the dam's total length of 67 m.

The structure is divided by expansion joints into sections (or monoliths) about 12 m wide, except for the abutment sections. The expansion joints are made of a joint-cover beam cast over a layer of synthetic waterproofing materials and a sealing plate.

The dam is equipped with an inspection and drainage gallery, which consists of two series of drainage pipes. After construction, the dam is approximately 14 m wide at the base and 4 m wide at the top.

Figure 1 – Cassiglio dam before (upper image) and after (below image) the works

1.2 The HPP

1.2.1 The hydropower groups

The power plant is located on the left bank of the Brembo River, near the Provincial Road “Piazza Brembana - San Marco Pass”, in the municipality of Olmo al Brembo (Bergamo, Italy).

The water used by the plant comes from two separate concessions. The water from the Cugno-Brembo diversion is conveyed to units 1 and 2 of the plant, while the water from the Stabina-Cassiglio diversion is conveyed to unit 3.

The unit of the Stabina-Cassiglio Concession was replaced with a similar unit consisting of a vertical-axis Francis turbine directly coupled to a synchronous generator, and the turbine's maximum flow rate was increased from 2.8 m^3/s to 2.9 m^3/s. The characteristics of the turbines are as follows:

Turbine Concession Stabina-Cassiglio

- Type Vertical-axis Francis
- Maximum discharge 2.90 m^3/s
- Head 98.5 m
- Power 2590 kW
- Velocity 750 rpm

The units of the Cugno-Brembo Concession were replaced with similar units, each consisting of a vertical-axis Francis turbine directly coupled to a synchronous generator. The turbine's maximum flow rate was increased from 1.25 m^3/s to 1.42 m^3/s per unit. The characteristics of the two units are as follows:

Turbine Concession Cugno-Brembo

- Type Vertical-axis Francis
- Maximum discharge 1.42 m^3/s
- Head 100.9 m
- Power 1299 kW
- Velocity 1000 rpm.

The water is released in the same channel for all the three hydropower groups.

The benefits of this project are the following:

- Increased efficiency of the production unit
- Increased reliability of the replaced components, which were old and largely obsolete

Figure 2 – Francis turbine – Cugno-Brembo Concession

1.2.2 The Cugno-Brembo penstock

The penstock is divided in two sections:

- The first section (upstream) is an underground reinforced concrete pipe with a diameter of 1.36 m, a length of 239 m, and an average slope of 13%.
- The second section (downstream) is a steel pipe with a DN1200 diameter, a length of 172 m, and an approximate slope of 60%.
-

The replacement of the existing pipe with a new DN1200 steel pipe was limited to the last above-ground section. The new penstock rests on new steel saddles set on small concrete slabs and is equipped with exposed anchor blocks fitted with clamps.

Figure 3 – Cugno-Brembo penstock

2 Description of the works

2.1 The Cassiglio dam

The static-functional upgrade of the dam included a concrete gravity block on the upstream face, with a variable thickness depending on the height. Within this new block, an inspection and drainage gallery was built, running parallel to the existing one. The connection between the old and new concrete sections was secured using stainless steel bars, anchored with resin into the existing dam body. The contact surface between the old and new concrete sections was prepared using hydro-demolition where necessary, and a layer of resin was applied to improve the adherence of the contact surface.

The new gravity block was likewise built in monolithic sections, aligned with the corresponding sections of the dam body. A joint was created between each section by inserting a double bitumen-elastomeric membrane.
The old dam body and the walkway over the spillway were raised. The old stilling basin was demolished to build a new one suitable for the new millennial flood flow value. At the end of the basin, a step measuring 3.10 m allows for the dissipation of accumulated energy by localizing the hydraulic jump and returning the water to the riverbed at critical velocity. Walls approximately 7 m high contain the fluid flow, even in extreme conditions during a millennial flood. The basin, with a thickness of 130 cm, is securely anchored to the bed via stainless steel bars grouted 120 cm into the riverbed's rock, arranged in a quincunx pattern with a 150 cm spacing.
The project also included the replacement of the bottom outlet gate and its associated equipment (hydraulic power unit, accessories, switchboards, and automation).

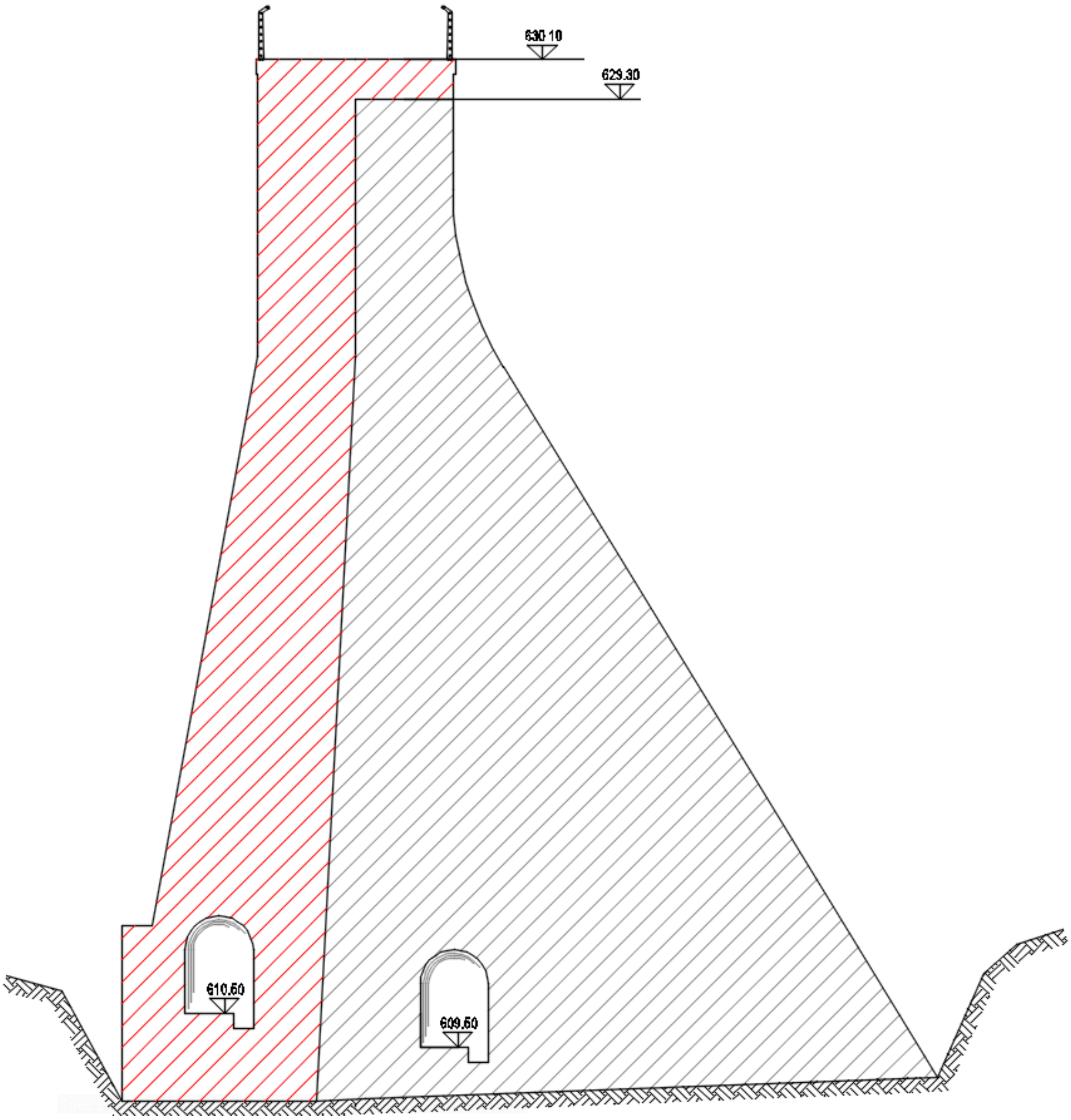

Figure 4 – Cross section type of the dam: the new gravity blocks are highlighted in red

2.2 Sediments removal

The Cassiglio reservoir has an active storage capacity of 56,000 m^3 at the maximum regulation altitude (626 m a.s.l.) and a total storage capacity of 81,000 m^3; over the years, the accumulation of sediment has reduced these volumes..

For this reason, an intervention of removal of the sediments was planned. Therefore, in conjunction with the necessary work on the dam, 46,600 m^3 of sediments were also removed to recover the active storage capacity. Heavy-duty trucks with three-axle trailers were employed to remove the sediments; each trailer has a gross vehicle weight of 26 tons, which is able to transport approximately 15-18 cubic meters of material, consisting primarily of gravel and silt. In total, approximately 2750 haulages were required to remove all the required volume of sediments.

Figure 5 – View of the lake bottom after emptying

2.3 The HPP

2.3.1 The hydropower groups

The construction site activities essentially consisted of:

- Site setup
- Installation of stop logs at the discharge of the units
- Removal of electromechanical works
- Removal of embedded parts through localized demolitions of existing masonry
- Installation of new draft tubes
- Preparation of formwork
- Installation of reinforcing steel
- Concrete casting
- Installation of new spiral casings
- Preparation of formwork
- Installation of reinforcing steel
- Concrete casting
- Assembly of the units, valves, and connection pipes to the penstock
- Casting of the valve blocks, generators, and pipes
- Installation of the closed-loop cooling system, complete with a heat exchanger, in the discharge channel

- Electromechanical and hydraulic connections
- Installation of switchboards and wiring
- Field signal checks
- Dry tests
- Wet tests
- First synchronization (first parallel)
- Dismantling of the construction site

2.3.2 The Cugno-Brembo penstock

The construction site activities essentially consisted of:

- Construction site access on private land and fencing
- Clearing of vegetation interfering with the removal of the existing pipeline and the installation of the new one
- Construction site setup through:
  - Delimitation with orange plasticized mesh fencing of the upstream area of the pipeline, where loading/unloading operations, concrete pours, site grading, and barracks installation were planned
  - Delimitation with orange plasticized mesh fencing of the downstream area of the pipeline, where loading/unloading operations, concrete pours, and site grading were planned
  - Installation of barriers to stop any material from rolling downhill
  - Installation of a lifeline at the masonry stairs
- Removal of the existing external pipeline (using a helicopter and a crane)
- Demolition of concrete anchor blocks using a diamond wire saw
- Demolition of the block under Provincial Road 1 using a hydraulic hammer
- Demolition of concrete support saddles with a hydraulic hammer mounted on a spider excavator
- Manual levelling of the foundation bed for the new saddles
- Casting of a lean concrete base for the new saddles
- Formwork for the new saddles
- Installation of reinforcing steel
- Casting of concrete for the new support saddles (with a concrete pump and a helicopter)
- Installation of the metal cradle
- Levelling of the foundation bed for the new blocks
- Casting of a lean concrete base for the new blocks
- Formwork for the new blocks
- Casting of concrete for the new anchor blocks (with a concrete pump and a helicopter)
- Installation of the new pipeline (using a crane and a helicopter)
- Hydraulic testing
- Dismantling of the construction site

3 Challenges and opportunities from simultaneous works

The most important opportunity from simultaneous works was the reduction of the downtime of the HPP.
This has been possible thanks to the phased start of the various works, which involved firstly the Stabina-Cassiglio concession with the works on the dam, and then the concession Cugno-Brembo with the works on the penstock; the works on the hydroelectric groups started at the same time the works on the penstock and after the start of the works on the Cassiglio dam.

The sediments removal was executed concurrently with the dam rehabilitation works. This integration was strategically advantageous, as access to the dam foundation—the reference point for the structural weighting—required prior clearance of the sediments, an operation that would have been necessary regardless. Furthermore, during the sediments removal, the access road to the work site and the channel leading to the dam's bottom outlet were constructed to manage the river flow.

The works on the dam involved simultaneously on both the downstream and upstream faces.
The works on downstream started from the first day of the works, while the upstream one started only when the activity of sediments removal reached the base of the dam; as the sediments removal works progressed, it became possible to carry out the drilling on the existing dam for the installation of the connection anchor bars.

	Month								
Works	1	2	3	4	5	6	7	8	9
Cassiglio dam									
Removal sediments									
Stabina-Cassiglio hydropower group									
Cugno-Brembo hydropower group									
Cugno-Brembo penstock									
Downtime Stabina-Cassiglio									
Downtime Cugno-Brembo groups									

Figure 6 – Works schedule and downtime

The challenges have been:

- Various works sites
- Respect of the schedule
- The management of various supplier

Thanks to the continuous presence of the designated client-side representative supporting the site project manager, the works were successfully completed without significant issues.

4 Challenges from works of weighting at the dam

The challenges of the dam's weighting have been:

- Monitoring and management of the temperature for the concrete maturation
- Bad weather conditions and the difficulties in managing the water discharge from the work site
- Transferring the formwork for the dam segments
- Scheduling the concrete casting and formwork stripping
- The construction of the new bottom discharge.
-

One of the main challenges for the realization of massive concrete castings is temperature monitoring and management; to do that, four thermocouples have been installed in four initial concrete blocks, with the purpose to know the temperature trend during the concrete maturation and define corrective measures to check the temperature.

The four thermocouples have been installed in different position:

- Central at the block
- Above the block
- Lateral the block
- External, to check the environment temperature.
-

For each of the four blocks, a diagram of the temperature trend was made; the temperature has been compared with various thresholds:

- Maximum temperature reach in the concrete core: 65 °C
- Maximum difference between the temperature of fresh concrete at the time of casting and the peak temperature measured in the core of the structure (thermal delta under adiabatic conditions): 35 °C
- Maximum temperature differential between the core and the external surfaces during the curing process: 25 °C
- Minimum environment temperature: 5 °C
- Maximum environment temperature: 30 °C.

A provision was made for each threshold:

- For the first three, application of wet non-woven fabric on concrete pours (horizontal surfaces), with the possibility of covering them with polyethylene sheets if the external temperature is high
- Insulation of the surfaces in case of low environmental temperatures
- Direct and continuous wetting of accessible poured surfaces immediately after the completion of vibration

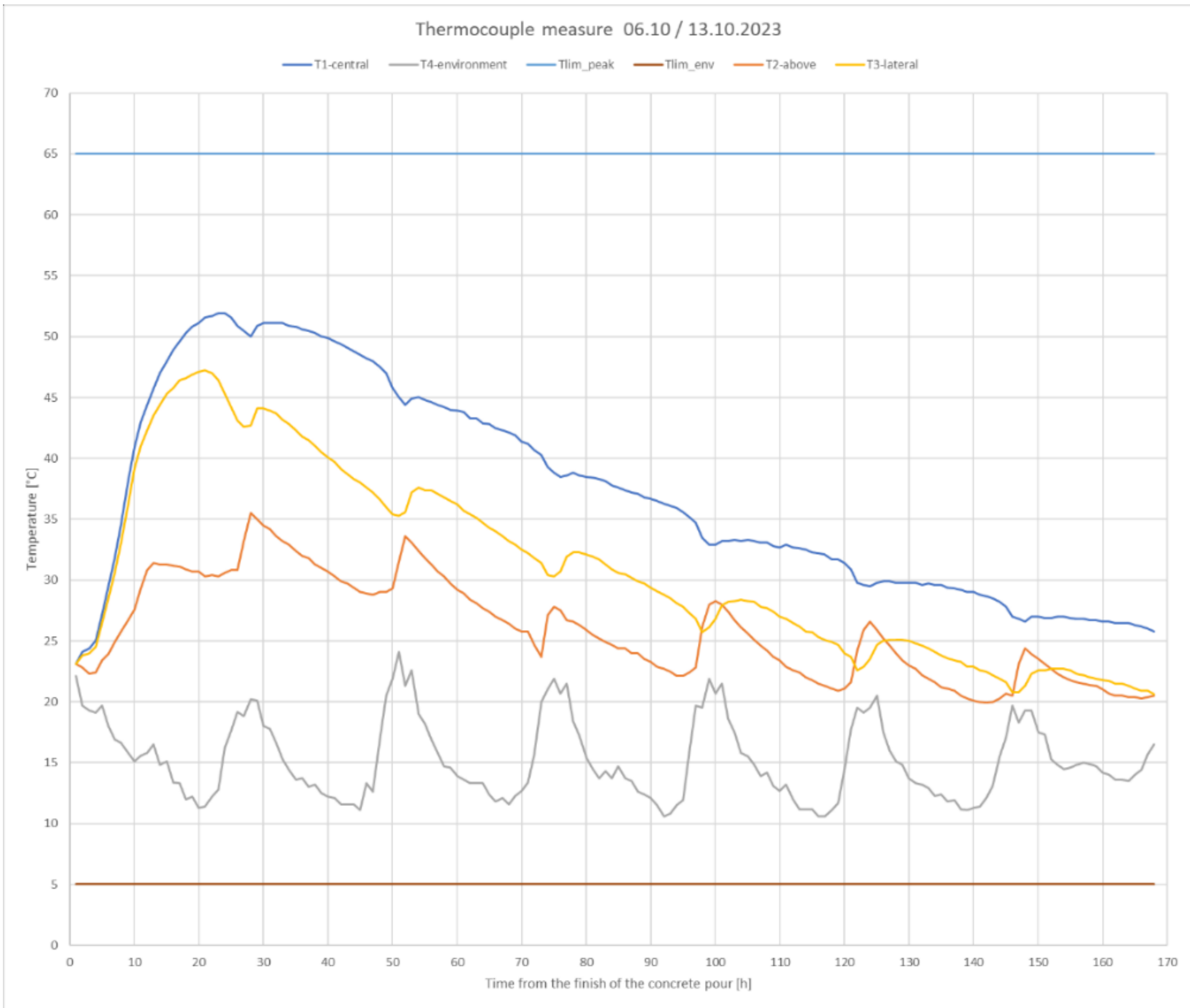

Figure 7 – Temperature diagram

The weather conditions stopped the works on the dam many times. Intense precipitation exceeded the flow capacity of the bottom outlet, resulting in multiple floods. These floods particularly affected the work site at the base of the dam, which lacked a natural drainage path due to being situated below the bottom outlet level. To manage the water in this area, various pumps were employed.

Figure 8 – Flood in the upstream dam site (with the firsts dam segments)

The concrete casting schedule was planned based on the results of pre-qualification tests. These tests showed that the formworks could be stripped after just two days of casting due to the concrete's high resistance, allowing for another casting to be done soon after. Moreover, the formworks could be easily moved and installed with a crane, speeding up operations and making it possible to build one block on top of another every 2-3 days.
For the construction of the new bottom discharge, water flow was managed by diverting it through the dam's drainage tunnels.

Figure 9 – The connection of the drainage tunnels of the dam

5 Challenges from the selection and on-site controls of the materials

Dams are built with specifical national rules that provide the pre-qualification of the concrete; the pre-qualification has the objective to check the useability of the concrete for the dam.

A lot of tests are done for checking the concrete, like:

- crushing tests at 2, 7, 28, 60 e 90 maturation days
- indirect traction tests
- freeze-thaw durability tests
- calculate latent heat of hydration of concrete
- density measurement

The concrete must satisfy the project standards, and the concrete must be approved from the dam's national regulator; only this concrete can be used during the weighting work.

A challenge has been the obligation to use the pre-qualification concrete, with the impossibility of add any additive that was not included in the pre-qualification procedure, like the antifreeze one; use a different concrete type would have been possible only after a new pre-qualification procedure (that would have required a suspension of the works at the dam).

But the principal challenge has been the management of the site controls of the materials. For the weighting of the dam have been used:

- 110 t of steel bar, used with the concrete casting
- 15 t of stainless-steel bars, used for the connection between the old dam and the new one and to connect the rock mass and the foundation of the new dissipation basin
- 5,300 m^3 of concrete, transported in the works site with around 600 concrete mixers

The steel bar checking hasn't been a big quest, because the regulation provides that for each transport and for each diameter three bars are picked up to undergo a traction test.
Instead, for concrete the regulation provided:

- 1 collection, made up of 8 cubic-shaped samples (150 x 150 x 150 mm), for every 100 m^3 of daily homogeneous concrete mix (minimum 1 collection at day) – for crushing tests at 7, 28, 60 e 90 maturation days
- 6 cylindric-shaped samples (ISO x 300 mm) every concrete casting week for indirect traction tests
- 4 cubic-shaped samples (150 x l50 x 150 mm) at least every concrete casting month for freeze-thaw durability tests
- Slump test for every day of the concrete casting
- Temperature checking.
-

Around 980 concrete samples have been taken.

The samples have been taken with the support of a company in-charge, with the supervision of the figure appointed to support site project manager client side.

6 Conclusions

Planning is the first step toward successful project completion. Forecasting various risks, anticipating them, and having emergency contingencies allows better control of the schedule and proactive management. The weighting of the Cassiglio dam, an activity on the critical path of the overall project timeline, was affected by several unforeseen events that jeopardized the completion of the work by the scheduled date. However, thanks to the synergy between the client's construction management team and the contractor, it was possible to deal with the various risks, even recovering time lost due to bad weather. The continuous on-site presence of the client's construction management assistant made it possible to monitor the supply of materials and to verify that the concrete samples taken during the pours were consistent with the project specifications.

Finally, the overlapping of work phases led to a significant reduction in plant shutdown time, thereby reducing lost energy production and allowing for an earlier return on investment.

The key lessons learned can be summarized as follows:

- During the pre-qualification of concrete mixes, it can be useful to include various mixes with different admixtures to be able to handle all situations
- It's necessary to always keep materials on-site to manage the temperature of mass concrete pours
- A system for controlling the concrete samples taken is mandatory
- Flood management systems must be oversized to avoid unpleasant site closures or damages (to equipment, concrete reinforcement, etc.)
- A strong direct correlation does not exist between the ambient temperature at the time of concrete casting and the characteristic strength of the test specimens; this conclusion was reached following a study requested by the regulator, which was based on thermocouple measurements and crushing tests

The Authors

M. Rebuschi, environmental engineer, graduated from Brescia University (IT); joined Frosio Next in 2020. He supported the *site project manager client side* during the construction of the upgrade of the dam.

E. Marchesi, hydraulic civil engineer, graduated from Politecnico di Milano (IT); joined Frosio Next in 2019. He supported the *site project manager client side* during the construction of the upgrade of the dam.

L. L. Papetti, hydraulic and chemical engineer, involved in the design and supervision of small hydropower plants since 1990. He is currently Chief Executive Officer and Technical Director of Frosio Next. He was the *site project manager client side* during the construction of the upgrade of the dam.