Challenges of construction in the southernmost part of the world

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A general overview of the main components of Argentina's Santa Cruz River hydropower development is presented here, including revisions made in recent years to original design, both to improve efficiency and to address environmental concerns. Socio-economic benefits of this major scheme are outlined, and a progress report from the site is given.

The Santa Cruz River hydropower project is a landmark initiative in Argentina's energy development strategy. Located in the southernmost region of the country, in the province of Santa Cruz, the project involves the construction of two large-scale dams: Presidente Néstor Kirchner and Gobernador Jorge Cepernic. These will harness the hydro potential of the Santa Cruz river for the first time, a resource studied since the 1970s. The project will also help to ensure long-term environmental, social, and economic sustainability in the region.

The combined installed capacity of the two Santa Cruz powerplants will be 1310 MW, representing approximately 5 per cent of Argentina's peak electricity demand. The expected average annual generation is planned to exceed 5000 GWh, contributing significantly to the national grid and supporting the country's transition to renewable energy sources.

1. Cepernic dam

Located 170 km from Comandante Luis Piedra Buena, the powerplant at the 41 m-high Gobernador Jorge Cepernic dam will have an installed capacity of 360 MW. The dam is designed to provide long-term benefits to the region and the country, including energy security, job creation, and increased regional development.

1.1 Construction progress and milestones

According to the latest reports, overall progress at the Santa Cruz River project has reached 45.4 per cent. Significant efforts are currently focusing on earthworks and preparatory operations for the river diversion, a critical milestone scheduled for 2027. More than 300 × $10^3 m^3$ of concrete has already been poured since the beginning of the project. In October 2023, the second turbine and associated components arrived from China, representing a total weight of approximately 6800 t of equipment.

The main embankment consists of approximately 6 × $10^6 m^3$ of various materials selected to allow for drainage of potential seepage while preventing the migration of fine particles. A cutoff wall ensures subsurface hydraulic sealing. The spillway includes five bays, each 12 m wide, with a total discharge capacity of 4163 m^3/s. A bottom outlet with a discharge capacity of 1200 m^3/s is integrated within the spillway structure.

1.2 Powerhouse and capacity

The powerhouse is a reinforced concrete structure with a metal roof, consisting of three modules, each 28 m long. It houses three Kaplan turbines, each rated at 120 MW. The plant is designed for base-load operation, with estimated annual generation of 1903 GWh.

The river diversion system consists of an open-channel trapezoidal canal, with a 120 m-wide base and 1 V:2.5 H side slopes. This canal will redirect the river flow from its natural course to the control structure during the construction phase.

The dam is in the middle valley of the Santa Cruz river, and is founded on alluvial deposits of gravel and blocks in a sandy matrix, with a good quality underlying rock mass. The cutoff wall is 80 cm wide and embedded to a depth of 5 m into the rock; it is constructed with alternating panels and joints to ensure continuity and watertightness.

The structural behaviour of the dam was analysed using a finite element model (Abaqus), taking into account static loads (self-weight, hydrostatic pressure, wave action) and dynamic loads (earthquakes). The model includes the actual construction sequence and material properties. Results show negligible displacements and plastic deformations, confirming the robustness of the design.

Since its original design, the project has undergone a series of strategic modifications to improve efficiency and reduce environmental impact. Key changes include:

- *Reduction in the number of turbines*. For the powerhouse at Cepernic dam, the number of units was reduced from five to three, to achieve a total installed capacity of 360 MW. This adjustment streamlines operations and reduces costs without compromising energy output.
- *Integration of a 500 kV high-voltage transmission line*. This was to improve connectivity with the national grid and enable efficient energy delivery.
- *Sixfold increase in bottom outlet discharge capacity*. This enhances operational flexibility, dam safety, and ecological flow regulation.

The Jorge Cepernic dam provides benefits to both Santa Cruz Province and Argentina as a whole. These include economic revenue (12 per cent of energy sales), job creation (6000 direct and 15 000 indirect jobs), clean energy, import substitution, complementary solar and wind projects, microclimate develop-

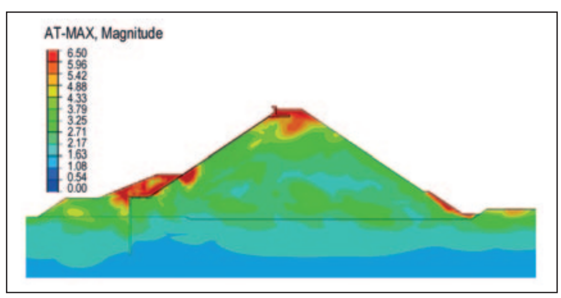

Fig. 1. Cross section of the Cepernic dam: Structural analysis.

ment, compensatory works in nearby towns, and support for electric transport and new industries. This clean energy output reduces reliance on fossil fuels and imports, contributing to the decarbonization of the national energy system.

2. Condor Cliff dam

The Néstor Kirchner hydro development has a long design history dating back to the 1950s, generally under the name 'Cóndor Cliff'. The first systematic studies defining a complete layout of the structures were conducted by the Argentine state-owned company Agua y Energía Eléctrica (AyEE) during the 1970s and 1980s. These studies established the current site for the project.

The general layout at that time consisted of a rockfill dam with a clay core, with all concrete structures located on the left abutment. The intake and spillway structures were aligned nearly parallel to the river flow. The dam height was greater than currently projected, and there subsequently some environmental constraints relating to the reservoir backwater, and the impact of this on Lake Argentino levels had not yet been considered.

2.1 Design optimization and project development

After successive iterations and analysis, the project evolved to how it is today, consisting primarily of a concrete-faced rockfill dam (CFRD) with a maximum height of approximately 68 m, and a powerhouse equipped with five Francis units, totalling 950 MW of capacity and an estimated annual generation of around 3200 GWh.

For the spillway design, the discharge flow was increased to approximately 4100 m^3/s. Regarding the powerhouse, the number of generating units was reduced to five, resulting in a more compact facility.

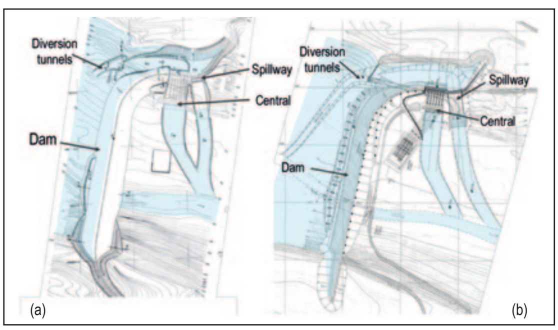

Fig. 2. General arrangement of the works (a) AyEE, 1970-80; and (b) basic design, 2012.

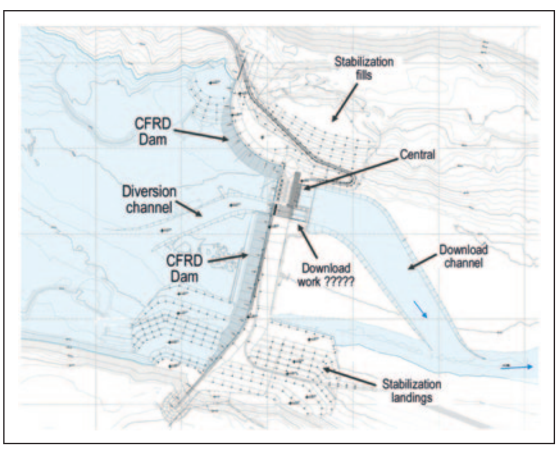

Fig. 3. General layout of the works, for the Optimized Executive Project, 2022.

Under the construction contract, the basic design was optimized based on available topographic, geological, and hydraulic conditions. To allow hydraulic separation from Lake Argentino, the normal operating level of the reservoir was lowered to el. 176.5.

2.2 Embankment dams

The Optimized Executive Project includes a main dam that closes the riverbed and most of the valley, extending from the right bank, where it curves upstream, up to the concrete structures, covering a total length of approximately 1250 m. The left bank is closed by a curved dam, extending from the concrete structures upstream to its anchorage in the abutment, with a total length of approximately 655 m.

The dams have an estimated maximum height of about 70 m at the current riverbed area and an average height of 60 m. They are embankment dams with an inclined concrete face (CFRD type), constructed using natural materials sourced from alluvial deposits found in the Santa Cruz river bed. The cross-section features upstream and downstream slopes of 1 V:1.5 H and a crest width of 12 m. The crest elevation remains unchanged from the Initial Executive Project at 180.6, with a wave-breaking parapet wall reaching a top elevation of 181.8.

Closure of the riverbed alluvium is achieved through the construction of a slurry wall and articulated plinth over gravel. The reinforced concrete slurry wall is 0.8 m-thick, built using 6 m-wide panels, and penetrates the full depth of the alluvium, being embedded about 7 m into the rock to achieve acceptable hydraulic gradients.

The drainage system consists of a continuous upstream-inclined drainage screen, incorporating a continuous lower drainage cord or mat along the entire dam, and the implementation of horizontal finger drains to allow adequate circulation of potential seepage collected by the drain. Fig. 4 shows a typical cross-section.

2.3 Bank stabilization

2.3.1 Right bank

Stabilization and reinforcement of the right abutment, both upstream and downstream of the dam, are achieved through fills complemented by a system of drainage galleries. These fills are planned in two stages. In the first stage, they will be developed up to the riverbank; then, once the river diversion has been completed, they will be extended into the riverbed to achieve safety factors compatible with final operating conditions.

The fills will be constructed using the same alluvial materials and construction methodologies as those used for the CFRD dams. The drainage gallery system within the abutment, along with the fill drains, completes the drainage system for the right bank.

2.3.2 Left bank

A fill was designed for the area downstream of the new structures, covering previously excavated areas up to the anchorage zone of the dam abutment. These fills have a crest elevation of 190 m. The slope between berms is 1 V:3 H, with a berm height and width of 10 m. The fills reach the toe at el.120 downstream of the structures, without interfering with the powerhouse discharge channel.

In addition, the toe of the curved dam was reinforced to improve the stability of both the dam and the abutment soils in the area with the steepest rock roof slope. Near the structures, this toe fill rises to el. 150, while in the abutment sector where the dam foundation rises, two fills were designed: one at el. +160 and another at +170 m. This approach strengthens the dam toe and improves the overall stability of the dam and abutment.

3. Concrete structure

The concrete structures associated with the Optimized Executive Project are concentrated on the left bank, and consist of a closure wall supporting the left bank CFRD, an intake and hydro powerhouse, and a discharge structure that integrates the spillway, river diversion works, bottom and mid-level outlets.

The intake structure consists of a gravity dam with five blocks, each 27 m wide, incorporating intake openings with protective trashracks. These lead into flared inlets that converge into 9 m-diameter sections, leading into the penstocks of the same diameter. Upstream, an emergency gate and a recess are provided to allow for installation of the cofferdam during maintenance.

The penstocks descend along the downstream face of the intake and feed the powerhouse, now located directly at the base of the intake. The powerhouse is equipped with five 190 MW Francis turbines, each with a rated discharge of 350 m^3/s, totalling an installed flow capacity of 1750 m^3/s. This equipment remains unchanged from the Initial Executive Project.

The discharge structure includes the spillway, bottom and mid-level outlets, the river diversion works, and the energy dissipation structure. On the right side of the discharge structure, a wing wall is provided for containment and connection with the main dam. Fig. 5 shows a cross-section of the structure.

The design includes a stepped chute which significantly reduces the energy to be dissipated in the stilling basin. An aeration ramp is provided to protect the chute against cavitation. Final energy dissipation is achieved through a hydraulic jump in a basin located at el. 97, and 100 m long. Downstream of the basin, a protection structure will be built.

The basin features a central wall that divides the spillway in two, allowing, among other things, the possibility of closing half of the spillway for inspection, maintenance, or long-term repairs without compromising the discharge capacity of the project.

There are four bottom outlets with a capacity of 1400 m^3/s, at el. 176.5. These outlets feature 3 × 4 m radial gates with a sill elevation of 122 m and upstream guard flat gates. A guide is also planned to allow for a third closure to facilitate general maintenance.

4. Summary and conclusions

The general layout of the works was optimized in successive stages, based on the available information.

Because of the characteristics of the site, with rock of variable composition and changing stratigraphy, covered by thick layers of glacial or alluvial deposits, the effectiveness of initiating deep excavations and works was demonstrated to observe singularities in the strata and/or their spatial continuity. The alluvium, glacial till, and their contact with the rock roof could be observed in detail through large-volume trenches.

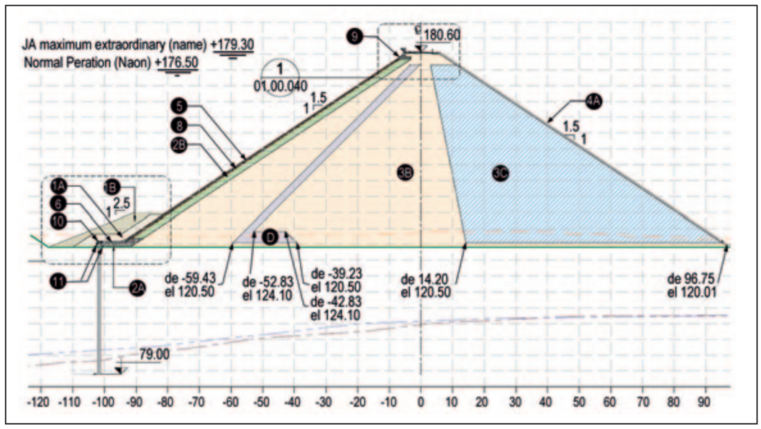

Fig. 4. Typical cross-section of the CFRD.

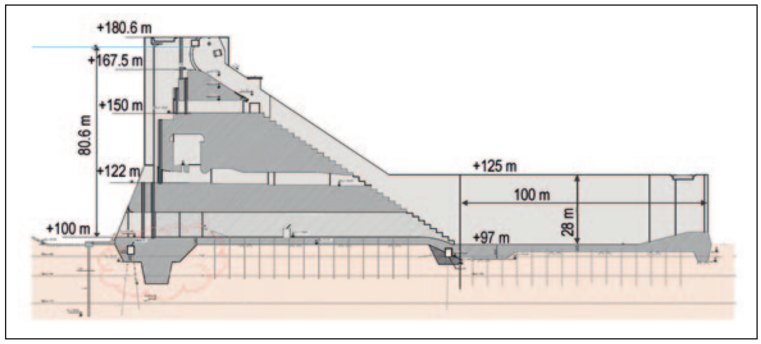

Fig. 5. Plan of the discharge structure: Optimized Executive Project.

To characterize the foundation rock mass precisely, it was necessary to create a large-diameter investigation shaft in the area of the structures to allow for direct observation of the rock and extraction of undisturbed samples for subsequent testing.

The Optimized Executive Project is fully developed and robustly addresses the singularities observed at the project site. Moreover, the hydro plants complement other renewable sources such as solar and wind, offering consistent generation even when weather conditions limit other technologies. This synergy strengthens grid reliability and supports a diversified energy portfolio.

The optimization of the Santa Cruz River hydropower project exemplifies how engineering, environmental planning, and social engagement can converge in a strategic initiative for sustainable development. In a global context demanding reduced greenhouse gas emissions, this project positions Argentina as a key player in the energy transition. ◊

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