39th IAHR WORLD CONGRESS GRANADA, SPAIN 2022 From Snow to Sea 19-24 June 2022

Proceedings of the 39th IAHR World Congress
19–24 June 2022, Granada, Spain
doi://10.3850/IAHR-39WC2521716X2022479

The legacy of hydraulic engineering: hidden treasures of Asturias

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Abstract

Hydroelectric energy will play a transcendental role in the ecological transition to green energy. Although the power of water has been harnessed by human beings since time immemorial, it was not until the Industrial Revolution that the first hydroelectric power plant was built. Electrical infrastructures of this kind were also built in Spain and Asturias during the 20th century, successfully contributing to the development of the region. This article takes a journey through the most unique hydroelectric infrastructures in the Asturian hinterland, describing their technical characteristics and historical context. It concludes with an analysis of the impact caused on society, the economy and environment of the region.

Keywords: Hydraulic Engineering; Industrial Revolution; Energy; Culture Wealth

1. INTRODUCTION

The dynamic movement of masses of water (kinetic energy) as well as the substantial differences in height (potential energy) provide the impetus for the production of hydraulic energy The use of this resource dates back to past times where the force of this fluid was used to move the blades of hydraulic mills (La Vanguardia, 2022). During the Industrial Revolution, the generation of electricity for the incipient industry (mainly iron and textiles) led to the construction of the first hydroelectric power plants. A good example is the Northumberland (United Kingdom) power station, built in 1880 to supply electricity to the surrounding textile industry (Hispagua, 2022). Since then, the construction of dams has become commonplace throughout the world, transforming societies, economies and natural environments immeasurably. With this in mind, recognition should be given to those pharaonic works such as the Aswan (Egypt) or Hoover (USA) dams (Berga Casafont, 1990; Francescutti, 2010), which are authentic milestones in world civil engineering. Nowadays, hydroelectric energy is the renewable resource that most contributes to the global energy market and is estimated to account for no less than 62% of all electricity produced by green resources (IEA, 2020).

On a smaller scale, the construction of hydroelectric dams in Spain represented an economic and social revolution in the country. Although in the Iberian Peninsula there are dams that date from the time of Ancient Rome, such as Proserpina and Cornalvo (Extremadura), it should be said that all of them were given over for irrigation and water supply (Castillo and Martínez, 1997; Arenillas Parra Marisa, Barahona Oviedo and Carmen Díaz-Guerra Jaén, 2007). It would not be until the beginning of the 20th century when, in the context of the *Plan General de Riego y Pantanos de 1902*, also called *Plan Gasset*, that the first hydrological plan in the history of Spain would be carried out (Aquaproomnibus, 2022). The purpose of this plan was the development and improvement of the agricultural and industrial sector, including methodologies for the provision of reservoirs. As a result of this plan, dams such as Cienfuens and San Bartolomé were inaugurated in 1908 in Aragón (Gran Enciclopedia Aragonesa, 2011). However, the fragility of the different governments during this time prevented the full development of the *Plan Gasset*.

Nor would it be until the 1930s when the first large dams in Spain were built in the framework of the Plan Nacional de Obras Hidráulicas de 1933. In this context, perhaps the most noteworthy is the reservoir at Ricobayo (Zamora) with a total capacity of 1145 hm^3 and whose design was made to produce electrical energy (López, 2015). Unfortunately, the outbreak of the Spanish Civil War in 1936 was a major disaster for the country's hydroelectric development, paralyzing all plans and projects for several decades. It was not until the 1950s when, in the context of the *Plan de Estabilización*, large hydraulic infrastructures were planned and executed. It is calculated that up to 615 dams were built in those years (Extremadura Digital, 2022). This meant an enormous increase in the country's electrical capacity, going from an installed power of 1.35 GW in 1940 to 12 GW in 1975, so that the industrial and urban demands could be adequately satisfied (el País, 1992). Figure 1 shows a timeline with the main milestones of hydroelectric power in Spain.

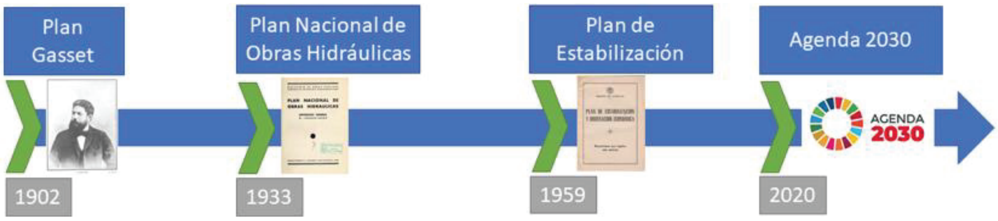


Figure 1. Timeline of the main milestones of hydroelectric energy in Spain.

In the framework of the Industrial Revolution, the region of Asturias located near the Cantabrian Sea, was one of the main industrial and mining areas of Spain. Although the first license for coal extraction in this province dates back to the 16th century (EMC, 2020), it was not until the 20th century when this activity was industrialized and became widespread. Specifically, in the decades with the highest extractions, Asturian coal represented 70% of the total volume of coal in Spain where the mines employed more than 12000 miners (EMC, 2020). This not only meant economic and social growth in the region, it also attracted the implementation of new industrial hubs related to the manufacture of steel and aluminum (Su et al., 2012). Thus, there was a significant increase in the electrical demands in Asturias, and a dynamic plan for the construction of new power plants was set in motion using the main resources of the area: water and coal. Therefore, thermal and hydroelectric power plants were built which amply covered electric demands.

The main characteristics of the Asturian orography include a rugged landscape teeming with deep valleys and copious vegetation. In addition, the region enjoys abundant rainfall, and values of 1200 mm of average rainfall are occasionally registered (AEMET, 2022). For that reason, an abundance of rivers with constant flow during the year can be found the length and breadth of the Asturian hinterland. Considering those characteristics, the construction of hydroelectric power plants is conducive to harnessing large waterfalls in a competitive manner and at a moderate price (Revista Ibérica, 1918). Thus, during the 20th century, hydroelectric plants were built in Asturias in the different river basins aimed to generate electricity to cover growing demands. Figure 2 shows a map of Asturias with the main river basins and hydroelectric power plants.

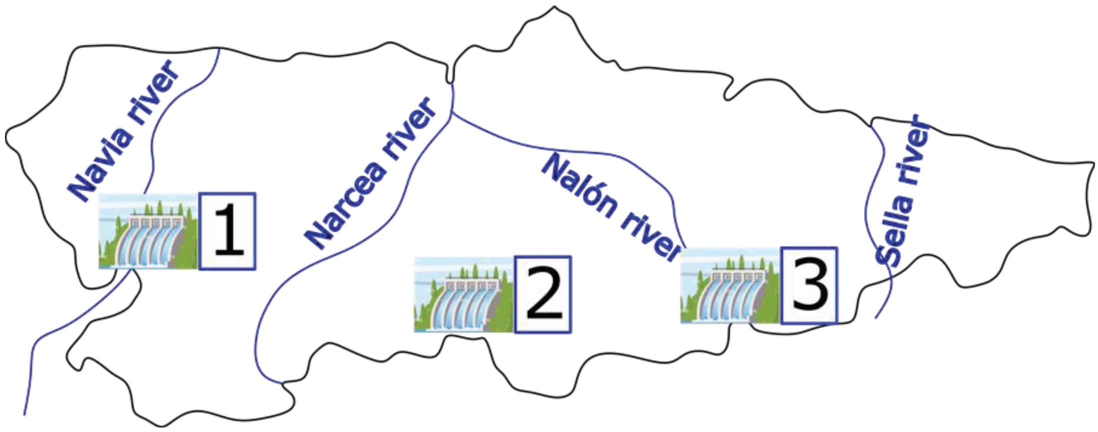


Figure 2. Map of the main rivers and hydroelectric power plants of Asturias: 1) Grandas de Salime, 2) La Malva and 3) Tanes-Rioseco.

The region has a total installed power of 777.9 MW largely attributible to the 40 dams which have a water capacity of more than 480 hm^3 (Invest in Asturias, 2022). The main river basins are the Navia River (2590 km^2) and Nalon River (3692 km^2), where singular hydroelectric power plants are located due to their technical and cultural characteristics. Some of these infrastructures were pioneers in their times due to their operational procedures and are still working nowadays. They were milestones in civil engineering, not only because of the magnitude of their infrastructure, but also because of the numerous technical, economical, and logistical difficulties that they had to overcome.

This article presents a compilation of the main hydroelectric infrastructures in Asturias, analyzing their historical and technical impact on the region and describing the main milestones reached during their construction. In addition, a study of the consequences that these infrastructures have had on the Asturian society, environment and culture is carried out; placing them in the historical context that originated the consecution of their works. Specifically, they are described as the dams of Grandas de Salime (Navia River), La Malva power plant and the hydroelectric pumping power plant of Tanes-Rioseco (both in Nalón River).

2. LA MALVA. BEGINNINGS OF HYDROELECTRIC POWER IN ASTURIAS

La Malva power plant is located in the borough of Somiedo and belongs to *Los Saltos de Somiedo* hydroelectric complex. Inaugurated in 1917, this structure is made up of different reservoirs, lakes, channels and tunnels located in Somiedo Natural Park, designated as a Biosphere Reserve in 2000 (RERB, 2022). Figure 3 shows a schematic diagram of the hydroelectric complex.

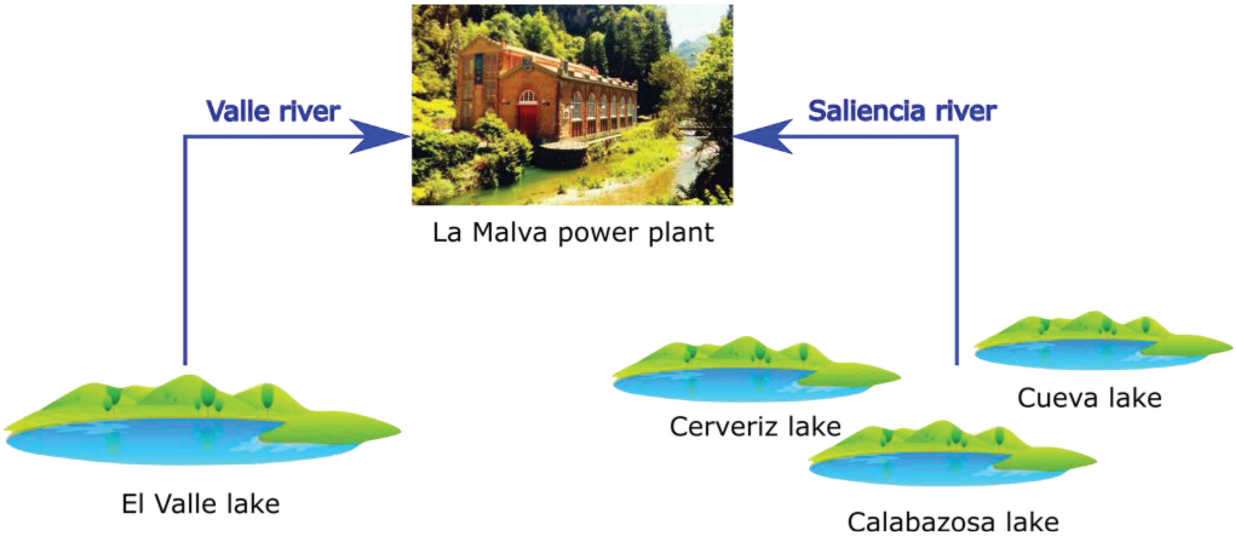
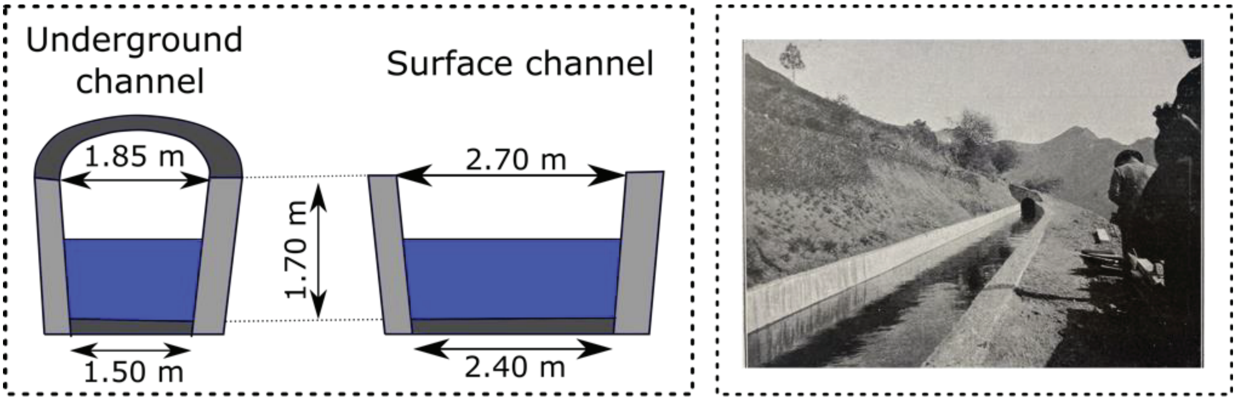


Figure 3. Diagram of La Malva hydroelectric complex.

The main water collection points are, on the one hand, El Valle lake (1484 masl) and, on the other hand, the Saliencia lakes formed by Calabazosa (1556 masl), Cueva (1491 masl) and Cerveriz (1648 masl). All of them obtain the water from the copious winter snowfalls, rain and groundwater from the karstic massif that surrounds them. In this way, they have a constant volume throughout the year, which means that their main effluents, the Valle and Saliencia rivers, have a constant flow rate. It should be noted that both rivers have a slope of 1000 m along 15 km, which produces substantial waterfalls (Revista Ibérica, 1918).

The building project for this hydroelectric complex began in 1909 and was the most advanced hydraulic project study in Spain at the time. Specifically, flow measures were carried out for several years by the construction of channels and spillway dams. In addition, temperature records were kept, and the course of surface and groundwater flows were verified by using the sodium fluorescence technique. Finally, pluviometry measurements were made using various meteorological stations. All this data was used to ensure the average flow rate of the power plant.

After carrying out the preliminary studies, it was concluded that *Los Saltos de Somiedo* complex has a river basin of 49.65 km^2 and the average flowrate of El Valle and Saliencia rivers is 1.63 m^3/s in a steady state. The water intake of the plant comes from two different systems: Valle Lake and Saliencia Lake. On the one hand, the Valle Lake system is an artificial reservoir formed by a concrete dam 4 m high and 40 m long that stores more than 2000 m^3 of water. This dam is connected to the Valle River through a concrete channel of 6.5 km long and a 0.1% slope that transports a maximum flowrate of 1.8 m^3/s. This infrastructure runs through a karstic massif with steep slopes, prompting the building of important embankments and tunnels. In addition, at some points along the channel, lateral spillways were installed to drain water during strong floods, creating artificial waterfalls more than 550 m high. On the other hand, Saliencia Lakes required the construction of smaller channels that discharge water directly to Saliencia river. Figure 4 shows a diagram and photograph of the El Valle channel.

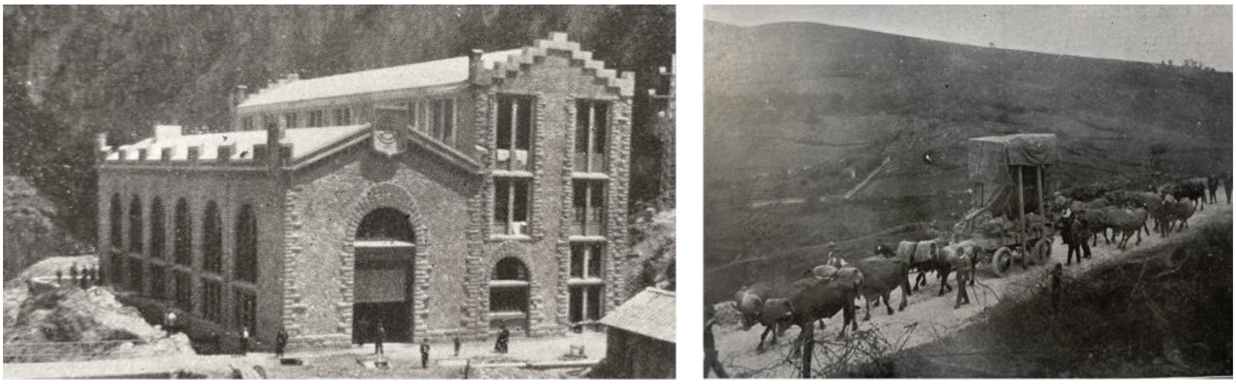


a) b)

Figure 4. a) cross-sectional view of the channel of Valle and b) photograph of the channel in 1918 (Revista Ibérica, 1918).

The aforementioned works would not be as important if they had been carried out in another location with better accessibility and a less steep terrain. In fact, there was an added difficulty in that the construction of secondary roads and tunnels in limestone walls was required to transport workers and materials. It should be noted that inconsequential accidents were recorded during this project.

All water flows converge into two high-resistance steel pipes of 1.3 km long and 800 mm of diameter, capable to work at a pressure of 55 atm. Both pipelines are responsible for supplying water to La Malva hydroelectric plant, harnessing a net jump of 550 m. The power station building is made up of bricks and is 42 m long, 24 m wide and 18 m high; requiring for its construction a manual excavation of more than 6000 m^3 of limestone rock. Inside, four Pelton turbines with a single injector and a power of 2.4 MW each were installed. It should be noted that the transport of these rotors was carried out by animal traction (Figure 5).



a) b)

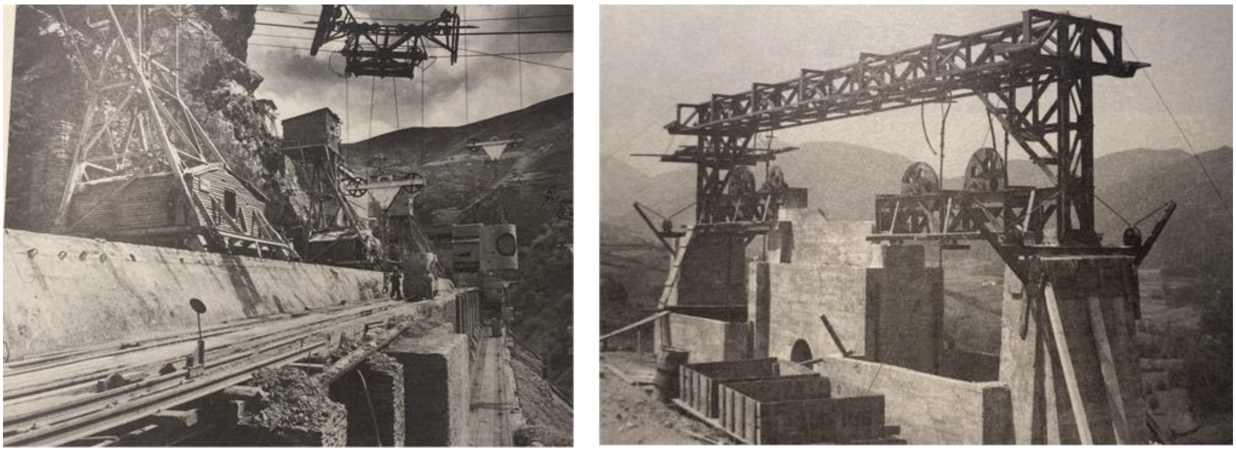
Figure 5. a) La Malva power plant in 1918 and b) alternator transport by animal traction.(Revista Ibérica, 1918).

Today, La Malva hydroelectric power plant is still operating more than a century after its inauguration, generating 38000 MWh/year due to the improvements in the design of the turbines. Recently and on the occasion of its hundredth birthday, a museum has been created with an excellent reception by the population (Ayto Somiedo, 2022). This small museum shows images, photographs and includes a visit to the hydroelectric power plant, which brings the history of this location closer to the public.

3. GRANDAS DE SALIME. TECHNICAL AND LOGISTICAL CHALLENGE

The dam of Grandas de Salime is located in the Asturian council of the same name and stores water from the Navia River. This rushing river of the north of Spain has an average slope of 0.45% and reaches a maximum flowrate during flood episodes of 118.84 m^3/s (CHC, 2022b). The construction of the dam began in 1946 when different works were carried out, such as the laying of railway tracks for earthmoving wagons, 35 km of roads and rock tunnels and 22 km of electrical and telephone lines (L. Lorenzo Pérez, 1954). All these structures were necessary in order to build the concrete wall of the reservoir and which nowadays are used by the inhabitants of the region.

The hydraulic structure is located in a deep valley generated by the Navia River and is 68 km from the coastal port of the town of Navia, making communication difficult. Thus, the transportation of materials was an arduous task that required ingenuity and technology. To bridge this distance, a 37 km-long cable car was built making it possible to pass through large valleys effortlessly. This cable car was made up of wagons with a capacity of 500 kg in which the necessary materials were transported to the dam. It should be noted that, at the time, it was the longest cable car of Spain and the most important in terms of load capacity of Europe (L. Lorenzo Pérez, 1954). In addition, to accommodate host workers, different villages were built, provided them with all basic services such as housing, hospital, school, and dining rooms. Figure 6 shows photographs of the cable car.



a) b)

Figure 6. a) cable-crane for materials and b) transport cable car from the port of Navia (L. Lorenzo Pérez, 1954).

Due to the high flowrate of Navia River, for the construction of Grandas de Salime dam, two cofferdams and a tunnel excavated in rock were built to divert its flow. Both cofferdams were made up of a concrete wall of 14 m high with Creager profile, while the tunnel has a total length of 625 m and a cross section of 22 m^2. These structures were demolished once the dam was completed and were essential to undertake it construction. Additionally, a quarry was exploited nearby for the in-situ manufacture of concrete and chemical and mechanical laboratories were set up with a view to analyzing those materials. Lastly, to ensure good performance in the construction procedure, a set of cable cranes were installed making it possible to reach the record working cycle of 163 m^3/h of concrete in a day.

From a technical point of view, the construction of the dam required the excavation of more than 303000 m^3 of hard rock, which was transported using cable cranes. Only in this way was it possible to build the 132 m high and 250 m long arch-gravity dam that can still be admired today. It should be noted that, in its time, Grandas de Salime was the highest dam in Spain, only surpassed in 1970 when La Almendra (Salamanca) dam reservoir was inaugurated (Navalón Burgos and Gil García, 2005). Not only that but it became a pioneer in its installation of a spillway of 2000 m^3 capacity with a Creager profile in its central body, located just above the hydroelectric power station. This plant is located in the body of the dam as there was no space for its installation out of the structure. It has four Francis turbines that harness a net jump of 112 m and accounts for an installed power of 30.4 MW each. Figure 7 shows photographs of the spillway.

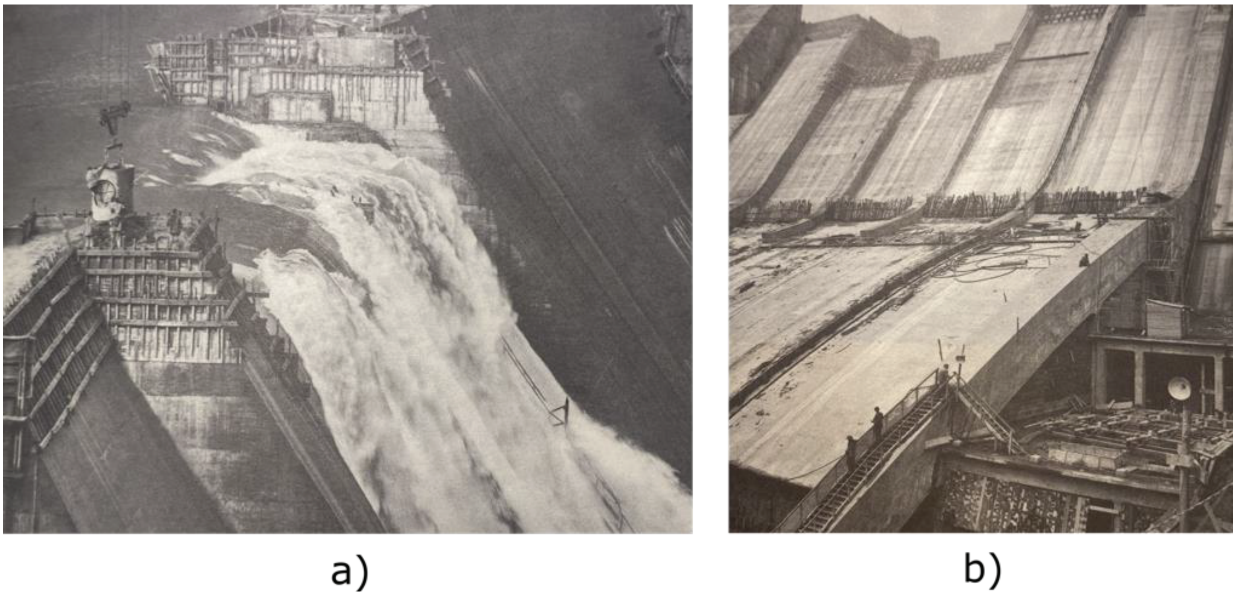


Figure 7. a) photograph of the spillway during a flood and b) spillway during its construction.(L. Lorenzo Pérez, 1954).

The dam has a maximum length of 30 km and contains a total water volume of 270 hm^3. For its construction, it was necessary to expropriate more than 680 hectares of farmland and livestock terrains, moving 13 towns elsewhere in the process. This undoubtedly caused an exodus of a large part of the population in the area, although new towns were built elsewhere to accommodate them. The total expropriation cost was of 5.7 million euros (L. Lorenzo Pérez, 1954).

4. TANES-RIOSECO. THE FIRST PUMPED-STORAGED POWER PLANT

The Tanes-Rioseco (pumped) hydroelectric complex is located in the Nalón river basin and, more specifically, in the heart of Redes Natural Park which was classified as a Biosphere Reserve in 2001 (RERB, 2022). Built in 1978, it is made up of two reservoirs: the lower one called Rioseco (Sobrescobio) and the upper one named Tanes (Caso). This singular type of hydroelectric power plant bases its operation on pumping water from the lower dam to the upper one in order to reuse it later in the production of electrical energy. Thus, the generation of electricity occurs at peak hours of consumption (high demand), while at times of lower demand (valley) the water is pumped to the upper dam, storing that energy for later use. It should be note that this procedure contemplates operating energy losses of the 25%, but these losses are lower than the ratio of generation costs between peak and valley hours (Marta Navarro, 2013).

The construction of this hydroelectric plant was carried out during the nuclear energy expansion plans in Spain that took place during the 1970s and 1980s (CSN, 2022). Thus, the excess energy generated by the nuclear reactors was used to pump water to the upper dam. Subsequently, this stored energy was turbined to adjust the demand curve with the electricity supply, increasing the flexibility of the energy market (UNESA, 2003).

From a technical point of view, Rioseco is a gravity dam of 29 m high, 100 m long and has a total water capacity of 4 hm^3. Its main use is to supply drinking water to the central area of Asturias (800000 inhabitants). Tanes dam is situated 6.5 km to the south of the Rioseco reservoir. This structure is a 95 m high gravity dam and 195 m in length.Between both dams there is a net head of 102 m in turbine mode and 105 m in pumping mode. The generation of electricity is carried out in an underground hydroelectric power plant formed by two reversible Francis turbines with an installed power of 125.5 MW each. Thus, the whole set allows the generation of 68000 MWh/year using turbines and 100000 MWh/year pumping (EDP, 2011). Figure 8 shows a diagram of the hydroelectric complex.

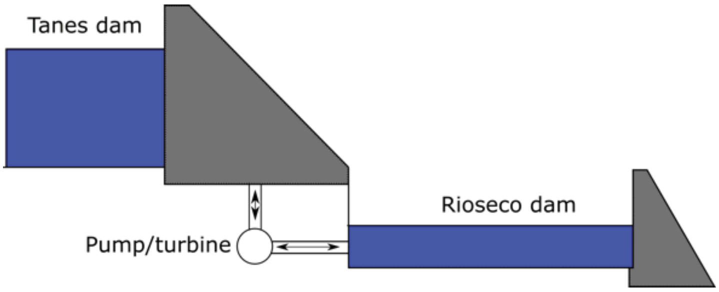


Figure 8. Diagram of Tanes-Rioseco pumping complex.

The construction of these dams required exhaustive planning of the logistics of the materials used, necessitating the expansion of the existing mountain roads and the use of the Gijón-Laviana narrow gauge railway. The latter elements made it possible to transport the materials 67 km from the port of Gijón to the location. Additionally, a system of cable cranes was built to apply concrete and transport the heavy machinery to the bottom of the valley (see Figure 9a). In addition, as the Nalón River has an average annual flowrate of 55.18 m^3/s (CHC, 2022a), it was necessary to build a cofferdam and a tunnel to divert its course (see Figure 9b).

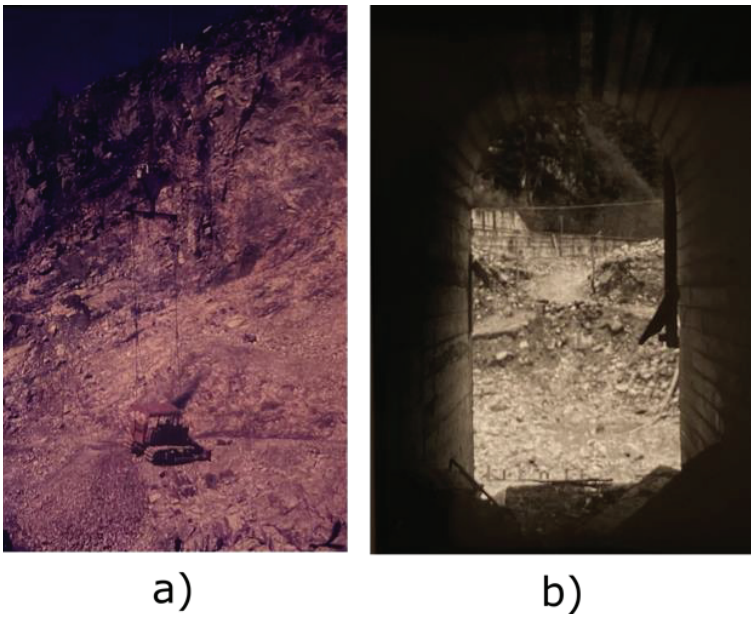


Figure 9. a) heavy machinery transported by cable and b) tunnel for river deviation.

One of the main milestones reached in the construction of this hydraulic complex was the development of experimental scale models to study the different transient phenomena that could take place at the plant. Specifically, tests were carried out to size the damping elements to absorb mass oscillation and water hammer phenomena. These effects are common in hydroelectric pumping stations where the pump-turbine group starts and stops regularly. In the specific case of Tanes-Rioseco, the scarce space available to undertake a surge chamber required the use of the most innovative experimentation techniques of the time. Due to this experimental study, it was possible to corroborate the design of the surge chamber, which was finally placed inside the karstic massif that surrounds the installation. The total height of this chamber was 71.5 m with a diameter of 16.6 m. Figure 10 shows some photographs of the tests carried out in the laboratory.

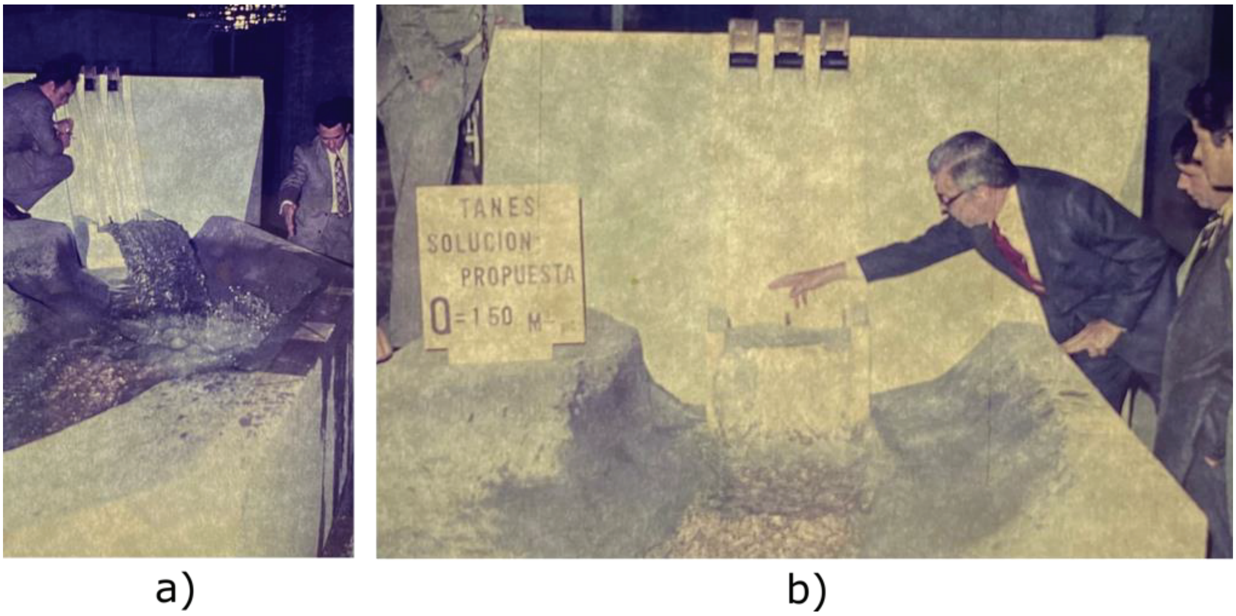


Figure 10. Photographs during the experimental tests on transient phenomena at Tanes hydroelectric power plant.

Nowadays, Tanes-Rioseco hydroelectric complex is the main source of drinking water in Asturias and one of the main renewable power plants in the region (CADASA, 2021). In addition, due to it privileged location in a natural park, both dams provide excellent locations for bird watching during the breeding and migration seasons. It should be noted that its construction has decisively influenced the region, causing a transformation in the productive sectors from a primary economy to a green tourist activity. In recent times, some proposals have been made to use Tanes dam as a place to practice water sports which would revitalize the economy of the region (el Comercio, 2021).

5. CONCLUSIONS

Hydroelectric energy is nowadays the most widely used renewable energy in the world and is destined to play a transcendental role in energy transition. Although the power of water has been harnessed by human beings since time immemorial, it would not be until the Industrial Revolution that the first large hydroelectric power plants began to be built. Thereafter, a series of dams were constructed throughout the world so that electricity demands could be covered.

In the case of Spain, the construction of this type of structure began later than in the rest of Europe. This was mainly because of strong social, economic and political instabilities that the country suffered during the 19th and 20th centuries. In this context, although the first hydroelectric plans began in the 1930s, it was not until de 1960s and 1970s when the largest reservoirs were built. This brought about a twelvefold increase in the country's hydroelectric power capacity.

This hydroelectric development also occurred in Asturias. This province in the north of Spain, with a long mining and industrial tradition, undertook various hydraulic projects that were the key to its economic development during the 20th century. For that reason, and due to the unique steep orography of the region, the most innovative engineering techniques of their time had to be applied. Some examples are the La Malva hydroelectric power plant dating back to the beginning of the century, Grandas de Salime dam and Tanes-Rioseco pumping power plant.

All these structures present special technical characteristics due to the historical context in which they were built and the state of the technology used during their construction. Thus, these three hydroelectric power plants represent the transformation of a region and have caused a major impact on population, the economy as well as the environment.

6. ACKNOWLEDGEMENTS

The authors of this article wish to thank the work and tenacity of all those workers who participated in the construction of these majestic engineering projects. To all of them, our heartfelt recognition.

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