A pioneering approach

Studio Pietrangeli has used innovative design solutions in many of the dams and hydropower projects it has worked on over the years. Report by **Giorgio Pietrangeli**, **Antonio Pietrangeli** and **Giuseppe Pittalis**

Right: **Drone survey at Gibe III in Ethiopia**

STUDIO PIETRANGELI (SP) CONSULTING engineers is specialised in the design of dams, hydropower projects, transmission lines and various large scale hydraulic projects. The company, based in Rome, Italy, was founded in the 1960s by Giorgio Pietrangeli following in the footsteps of his father, Francesco Pietrangeli, who started his professional career as a hydraulic engineer almost one hundred years ago in 1922.

To date SP has been directly responsible for the design of 262 dams, 117 hydroelectric projects, more than 500km of waterways, water transfer schemes and HV transmission systems including over 8000km of HV transmission lines.

The company's engineers have developed their skills and experience working mostly in Africa, Europe and South America. Several of SP's projects, given their innovative, non-conventional approach and importance have been written about and/or cited in prestigious magazines, such as National Geographic and The Economist. SP is an entirely independent, family-run business where technical qualifications, culture and creativity merge to find solutions to complex and challenging engineering problems.

Below: **Helicopter survey along the Omo River in Africa**

Trends in the design approach

Design solutions have naturally evolved over the years in relation to the increased use of new technology that allows complex tasks to be performed much more quickly and easily than in the past when they took far longer and involved considerable resources.

Large computational capacities allow the company to perform complex 3D hydraulic/stability/thermal analyses of hydraulic structures. New technologies (eg. remote sensing techniques, general circulation models, tomographical geophysical methods and so on) mean the company can acquire, in a very short time, basic topographical, hydrological and geological data that are essential for the development of preliminary but reliable project layouts.

Modern technology sometimes confers a new lease of life to relatively old and out-of-date investigation methods. For instance, photogrammetric techniques widely used at the beginning of the last century have again become extremely popular thanks to the use of drones. SP has successfully pioneered the use of drones in the field of dam engineering in a wide range of contexts and environments the world over, totalling hundreds of hours of flight time to obtain detailed topography, digital terrain models, close mapping of structures, geo-structural foundation mapping, video reporting of construction activities and so on.

Above: **The Studio Pietrangeli team – early investigations at Koysha**

The ability to communicate in real time, to manage, store, analyse and share the large amounts of data made available by the new investigative methods and by the enormous computational capabilities that are accessible nowadays requires special skills. This is another important trend in the company's design approach that has been seen to be particularly urgent and necessary in this difficult time characterised by the Covid-19 pandemic.

SP's approach to the use of pioneering technology in its design activities is, however, always guided by a methodological approach rooted in the beliefs of the great philosophers of the past, starting from Galileo and Descartes who established the "rules" of scientific method in the "Discourse on Method" 1637.

Rule number 1 – evidence – concerns acquisition and validation of data. Following Descartes' approach, SP uses inhouse resources to carry out all the critical investigations and basic studies, i.e. topography, geology, in-situ tests, hydrology.

Over the past five and a half decades SP has passionately embraced this philosophy, experimenting with new technological ideas and exploring the possibilities of avant-garde inventions in data acquisition.

That is why much of the company's energy and general resources are spent in exploring new, more reliable and accurate means of acquiring dependable data upon which to base our designs.

Innovative design solutions

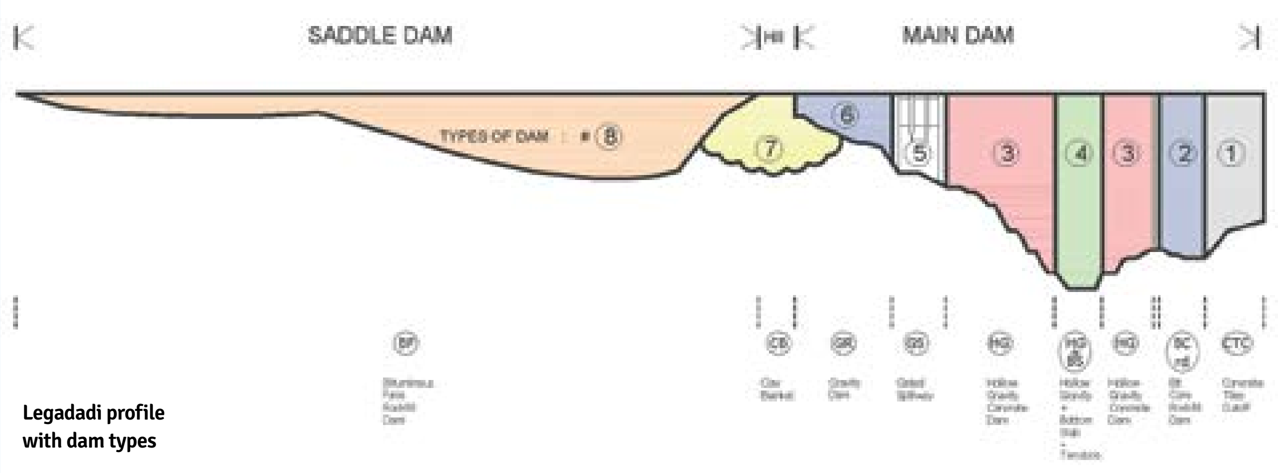
Over the years, SP has designed numerous large hydropower plants totalling 38,650MW. The most remarkable projects currently under construction or recently commissioned include Bumbuna (50MW) in Sierra Leone; Beles (460MW), Gibe II (420MW), Gibe III (1870MW), Grand Ethiopian Renaissance Dam (5150MW) and Koysha (2160MW) in Ethiopia. All the engineering services for these plants were, or are being, performed entirely by SP.

For most of these projects SP's so-called "fast-track" implementation method has been adopted.

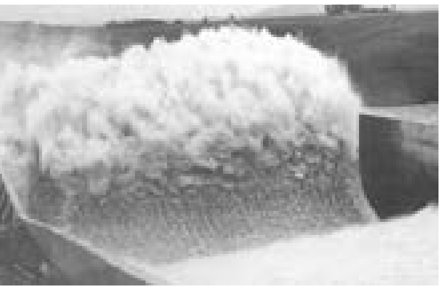
The basic concept of this method is to implement as many critical operating phases as possible simultaneously thereby drastically reducing (in some cases up to 30%) the total construction time. Thus the "fast-track" plant starts producing benefits and income long before traditionally built plants, generating a much quicker economic return against a minimum (or no) increase in upfront costs.

The following projects, briefly illustrated, have been selected to show some of the innovative solutions and unusual approaches adopted by SP.

Below: **Mr Pietrangeli pictured with the Emperor of Ethiopia, Heile Selassie. The Legadadi Dam was completed in the 1960s and was one of the first projects designed by Studio Pietrangeli to alleviate the chronic shortage of water due to the rapid expansion of Addis Ababa**



Legadadi profile with dam types



Above: **Spillway test at Legadadi**

Below: **Bumbuna operation scheme**

Legadadi (Ethiopia)

The Legadadi dam was completed in the sixties and was one of the first projects designed by SP to alleviate the chronic shortage of water due to the rapid expansion of Addis Ababa.

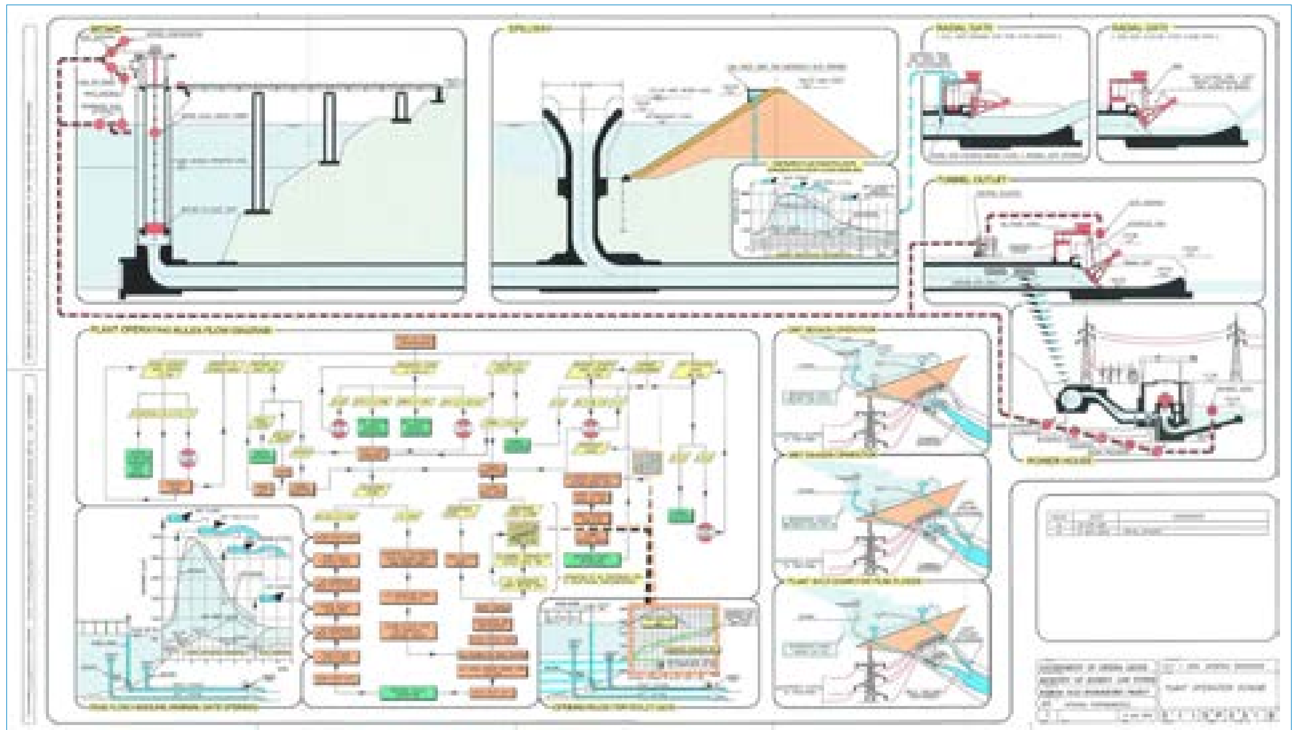
The dam, 60m high with a storage capacity of about 65Mm^3, includes several unique features. It is a so-called "tailor-made" dam where the dam type was modified to better cope with local geotechnical conditions randomly variable along the dam length. The right bank is constituted of a "concrete-tile" cut-off and a bituminous central core rockfill dam. The central portion is a concrete buttress dam while the left bank combines a gravity and a bituminous faced rockfill dam.The design of the joints between adjacent structures was particularly challenging and the adopted solutions have been cited in several technical manuals.

Another example of non-conventional design in this project is the energy dissipator. The unconventional design of this structure was tested in a UK laboratory but despite the positive results, the construction supervisors remained unconvinced. To demonstrate the soundness of his design, the engineer decided to create an artificial flood equivalent to the 1000 RP while dam construction was under completion. This exercise had never been tried before but it served to convince everyone that the non-conventional solution would work and has continued to do so for 50 years.

Bumbuna HPP (Sierra Leone – 50MW First Phase)

Bumbuna is the first large hydropower project in Sierra Leone and was a fundamental milestone for the development of the country. It includes an 88m high rockfill dam, a semi-outdoor powerhouse and a 161kV transmission line, 200km long, from the power station to Freetown.

The multipurpose waterway is the most original part of this project. It serves four different purposes: river diversion, power tunnel, spillway and bottom outlet.



The development of this unconventional solution was dictated by severe financial constraints. Had this solution not been adopted, Phase 1 of Bumbuna would have been postponed probably indefinitely, to the great detriment of the country's economic development.

The complex operation is controlled by a very innovative type of gate inspired by the Odysseus bow, with a "palintonos" shape made from three materials with differing elasticities: wood (taxus baccata), horn and sinew.

The relatively small amount of energy employed by the archer's arm to tension the bow-string is released very rapidly generating great power. Similarly, the fast gate manoeuvres as necessary to control incoming floods generating a pressure wave with great power but relatively little energy. The gate was designed to dampen the shock-waves by the deformation of the different materials that constitute the structure.

The conceptual design of the waterways and of the gate was tested in the Imperial College in London and presented in a technical paper published in International Water Power and Dam Construction in May 1994 and it has been in operation for about 15 years.

Gibe III HPP (Ethiopia – 1870MW)

Gibe III is the third plant of the Gibe-Omo cascade comprising Gilgel Gibe (200MW) and Gibe II (420MW), both operating, and Koysha (2160MW) under construction. The project itself is innovative and includes several outstanding key features. The RCC gravity dam, 250m high, is the world's tallest of its kind, creating a reservoir with a volume of 15,000Mm^3. The various RCC mixes used in the dam have a rather low cement content, varying from 70 to a maximum of 120kg/m^3 in the upstream zone. Most of the dam was built using an Ordinary Portland Cement (OPC) with low heat of hydration specifically manufactured in Ethiopia after extensive laboratory and field tests carried out together with the main contractor and principal Ethiopian cement producers.

The spillway on the dam crest controlled by seven radial gates 12 x 17.5m, is designed to discharge up to 18,000 m^3/sec, more than 200m above the riverbed in a rather limited area between the dam downstream toe and the powerhouse.

The river diversion system, designed to discharge up to 5200 m^3/sec, includes a 50m high rockfill cofferdam that was completed in only a few months using an innovative zig-zag geo-membrane core.

Grand Ethiopian Renaissance Dam (Ethiopia – 5150MW)

Once completed, with 5150MW of installed power and 15.7TWh of annual energy production, Grand Ethiopian Renaissance Dam will be the largest hydroelectric power plant in Africa. Located on the Ethiopian Blue Nile, about 40km east of the Sudanese border, the 175m high, 10.2Mm^3, RCC gravity dam will create a reservoir of about 74 billion cubic meters, one of the largest on the continent. The project includes a concrete faced rockfill saddle dam 60m high and 5km long with an embankment volume of 17Mm^3.

A system of three spillways safeguards the project against the Probable Maximum Flood (30,200m^3/sec peak and 18,000m^3/sec routed discharge).

One of the key issues of the project is the phasing and management of the river diversion, which is designed for a peak flood of 14,700m^3/sec. The dry season floods (from December to June) are discharged by a system of four culverts with an octagonal section 7.5 x 8.3m. The wet season floods, given their enormous magnitude, cannot be discharged by standard hydraulic structures and are therefore released by a temporary stepped spillway designed in the central part of the dam between the two powerhouses located at the dam toe on the right and left banks of the river. ●

Top: **Gibe 3 spillway discharging 3200m^3/sec**

Above: **Gibe III spillway. The photo shows the 11,000m^3/sec floods overtopping the RCC dam recorded in August 2020**

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