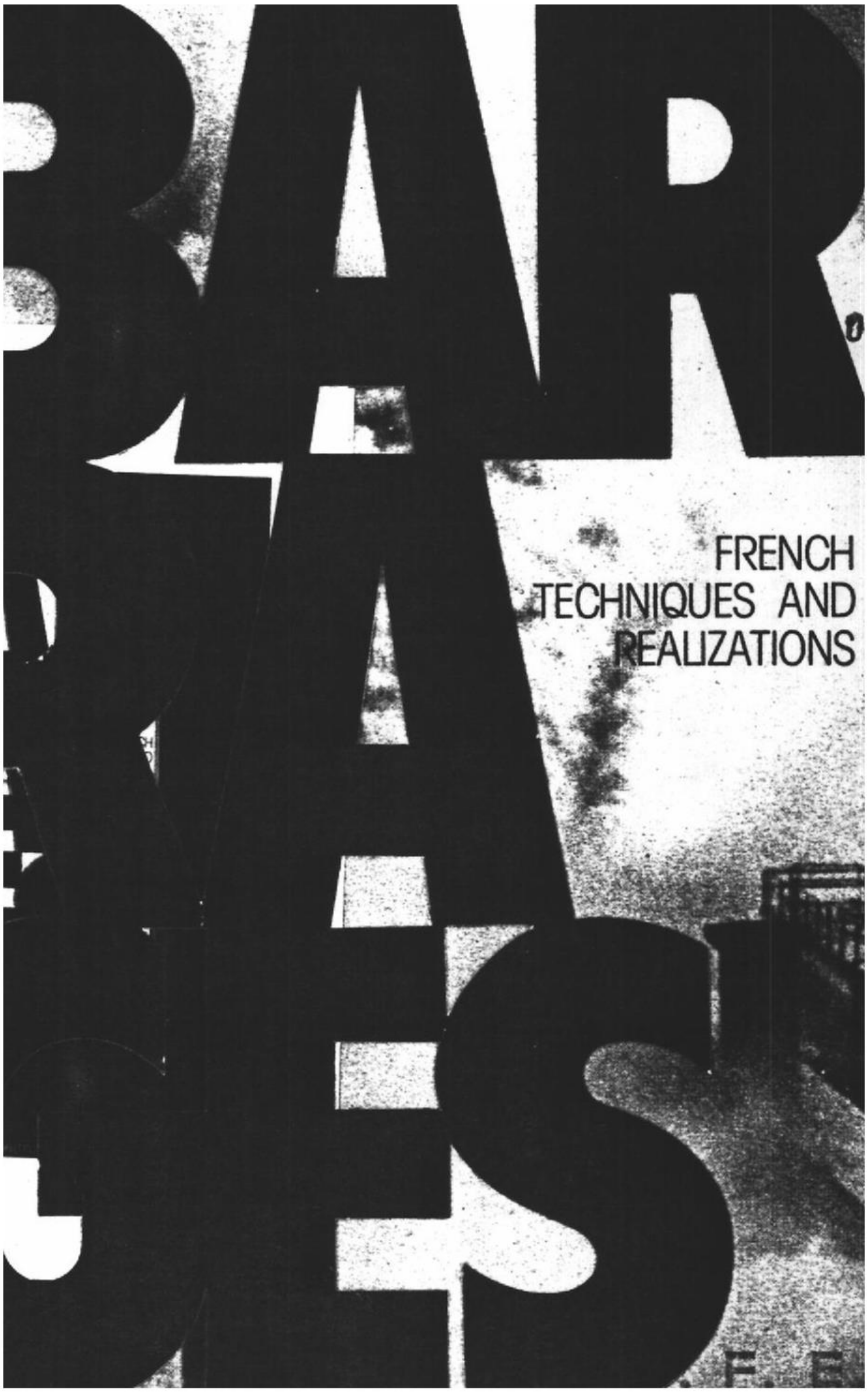

FRENCH
TECHNIQUES AND
REALIZATIONS

TABLE OF CONTENTS

FOREWORD

Dams, and hydraulic projects in general, are fundamental elements in the development of a country - even more so for those called "developing countries". Truly fundamental, since they have determining effects on energy production, irrigation, water supply for domectic as well as industrial use, flood and low water control, leisure activities, and even tourism.

In the vast, multifaceted domain of dam design, construction and operation, French firms and engineers can avail themselves of an extensive experience acquired over many years, as is amply proved in outstanding realizations the world over.

This brochure has been realized by the French Direction of International and Economic Affairs with technical advice from the French Committee on Large Dams. It aims at promoting in foreign countries, the high level of skill and ability of our owners, consulting engineers, contractors and manufacturers.

It represents a new step on the road to an even closer, more trusting collaboration between French specialized engineers and technicians, and the dam owners in foreign countries who will call upon their expertise.

Yves COUSQUER
Director of International
and Economic Affairs

Michel CARLIER
Chairman of the French
Committee on Large Dams

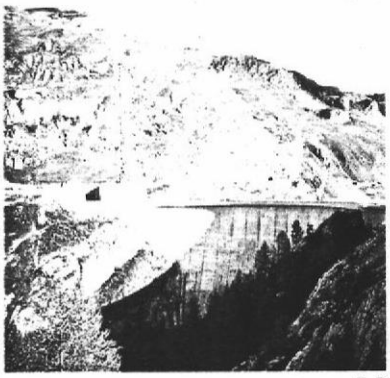
Importance of french technology

The study, design, construction and operation of dams bring into play a large variety of sciences and techniques: geology, hydrology, hydraulics elasticity theory, materials strength, soil mechanics, rock mechanics, etc.
The contribution of French scientists and engineers to the development of these sciences and techniques is considerable: it comes as no surprise, then, that the history of dam building should demonstrate the prominent role played by France in the domain of the study and design of these structures. A sampling of such realisations, to be seen in France as well as in other countries, can be found in the following pages.

History

As early as the XVIIIth century, research and experiments by Darcy in hydraulics, and Coulomb in soil mechanics, made it possible to lay down some fundamental laws, which even today are the basis of all design studies for earth dams.
One century before, (1675), the Saint-Ferréol dam, built by Riquet to feed the Canal du Midi, already was an exceptional structure, and created a world record for the height of an earth dam (36 m); it is still in operation.
However, whereas British engineers continued to build earth dams into the XIXth century, the French switched to masonry. This was a remarkable field of application for the materials strength and elasticity theory in which great French engineers such as Navier, de Sacilly, Delocre and later Pigeaud would become famous. Gouffre d'Enfer gravity dam dates from that period; built in 1866, it established, in its time, a world record for height (60 m), and it is still in operation.
It took the failure of Bouzey dam, in 1895, for Maurice Levy to explain a mechanism which is classical today, but was then completely unknown: the uplift caused by water seepage through the masonry of a dam.
Then came the "age of the arch". Already years ahead of his time, in 1854, François Zola, the novelist's father, had built a masonry arch dam near Aix-en-Provence (fig. 1-1).
But the real development of the arch dam, which came close to a century later, is due mainly to André Coyne. Under the leadership of this great engineer, the French technique made fast progress in this field, and placed France at the first rank of the builders of arch dams, which have become increasingly lighter, safer, and more economical. Deserving special mention are the great arch dams of Marèges (1935-height 90 m), Castillon (1948-height 101 m) (fig. 4-7) and Tignes (1952-height 180 m) (fig. 1-2).
In wide valleys where the classical arch dam would not be suitable, but where the rocky foundation permitted building a concrete dam, the buttress and multiple arch type has

1-1



1-2

1-3

1-1
Built on the Infernet river by François Zola, this arch dam became operational in 1854.
Height; 42 m;
crest length : 66 m;
volume of the dam : 7 000 m^3;
storage capacity : 2.5 million m^3.

1-2
Tignes arch dam, on the Isère river.
Height : 180 m;
crest length : 375 m;
volume of the dam : 635 000 m^3;
storage capacity : 230 million m^3.
Operational : 1952.

1-3
Girotte multiple arch dam on the Dorinet river.
Height : 48 m;
crest length : 507 m;
volume of the dam : 120 000 m^3;
storage capacity : 50 million m^3.
Operational : 1948.

CHAPTER 2

Investigation of natural data

Designing and building a hydraulic scheme requires knowledge of certain natural characteristics of the site, which are mainly of hydrological, topographical and geological nature.

Hydrological data

In the plains, rain and snow are evaporated by the soil and vegetation, whereas in mountain regions, a proportion of the rainfall, which can be as much as several meters on the more exposed slopes, goes to feed the torrents, whose flow depends on the drainage area, relief, and geological nature of the soil, as well as the vegetation. A smaller proportion of the rainfall is infiltrated and feeds the acquifer.

Therefore, any hydrological study must begin with the analysis of these factors, whose complex and interelated actions determine the quantities the project engineer seeks to define:

- average flow into the area,
- seasonal variations (or regime)
- extremes of flow: low water and flood levels,
- amounts of transported sediments.

Three approaches are combined to obtain evaluations of flows which come as close to reality as possible:

- direct measuring,
- comparing, with or without models,
- statistical analysis.

DIRECT MEASUREMENTS

On site direct measuring should always be preferred to an estimation; but lack of records over long periods, on the site, often leads to reasoned interpolations, and comparisons with results obtained by existing stations.

A network of hydro-climatological measuring stations is a priceless long-term investment for a country. On its metropolitan territorial area (550 000 km^2), France has built a climatological network whose 3500 stations are run by the Météorologie Nationale, and a hydrometric network of 2000 stations, some of which have been operating for more than 50 years. All the recorded information is fed into data bases which are computer processed for the most part.

Among the developments achieved in the field of data acquisition and processing, we may mention the following:

Rain- and snow-falls: generalized use and miniaturizing of tipping buckets and their adaptation to climates with heavy snowfalls (fig. 2-2).

Snowmelt storage: automatic measuring of the snow cover by action of a radioactive source (caesium 137) on the molecules of water (fig. 2-2). The measures are relayed by the Argos satellite.

Stream flows: the large scale application of flow measuring by dilution is especially suited to mountain torrents as well as rivers with high sediment content in the plains. Flows of up to 1000 m^3/s have been gauged with a sodium bichromate tracer in the loaded waters of Madagascar.

Sediment load: measure of siltation of reservoirs by ultrasonic sounding (full reservoir) and stereophotogrammetric survey (empty reservoir).

Recording and collecting of measures: independent magnetic recording on cassettes (fig. 2-3) operates between -30 and +60 °C, on an ordinary battery, with a capacity of 10 readings per hour for two months. The recorder is linked to a computer which allows immediate use of standard processing programs without tedious graphical derivation or recording:

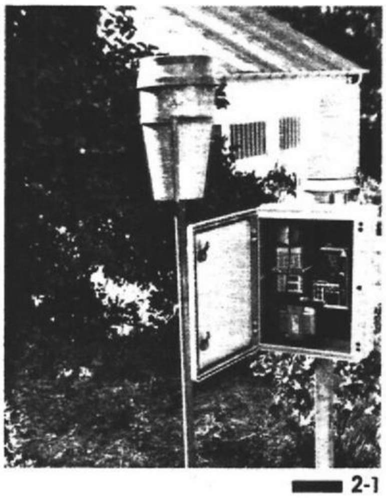
- depth to flow equivalence,
- printings of daily flow tables,
- recording of hourly levels and rainfall,
- printed or on-screen display of comparative results,
- etc.

A new stage is being developed: storage of hourly or semi-hourly values in a static memory, next to each measuring unit and collecting of data via telephone or satellite.

Small drainage areas: a special series of experiments, involving all hydrological parameters, is being run on the small drainage areas.

COMPARATIVE STUDIES, WITH OR WITHOUT MODELS

The methods used to extrapolate and/or correlate data from a nearby drainage area are now common knowledge. Objective metho-



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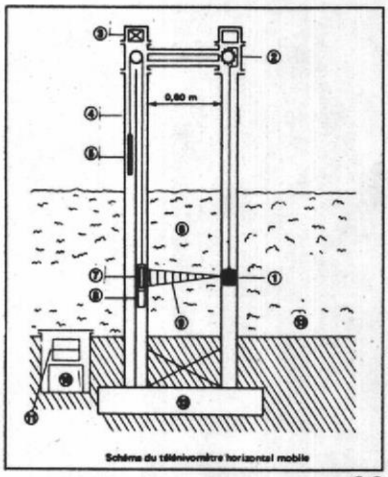


2-2

2-1
2 dm^2 rain gauge with 2 g tipping buckets, and electric supply box for the heating and cassette recorder (on the side, 4 dm^2 rain bucket).

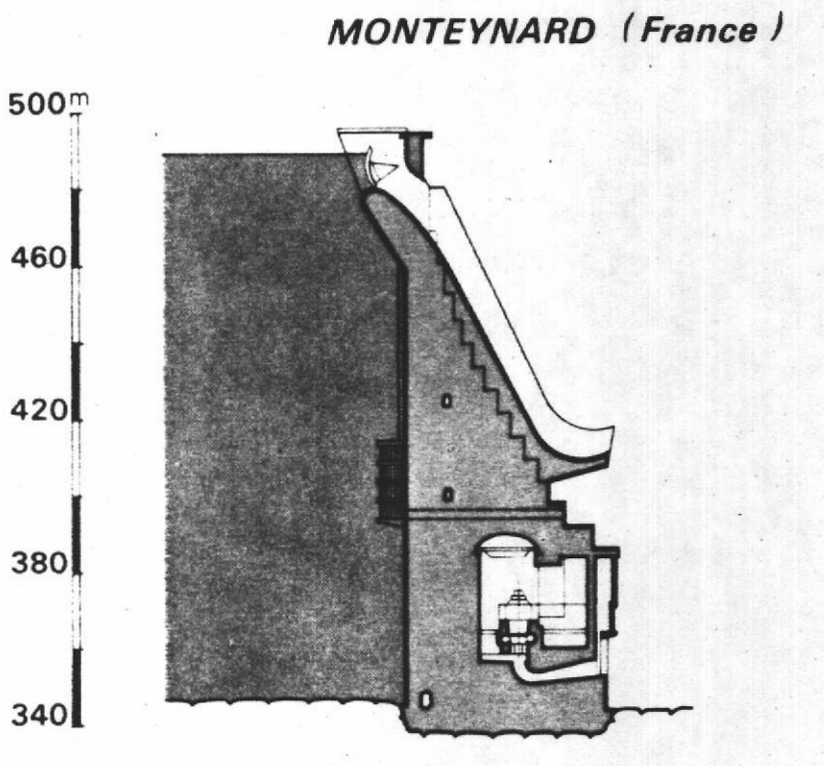
2-2
Mobile horizontal beam telemetering snow gauge:
1 - radioactive source 10 mCi Cs 137,
2 - stepping motor, reduction and sprocket drive,
3 - counting and programing electronics,
4 - light alloy posts, 5 to 6 m in height,
5 - counterweight,
6 - snow,
7 - GM detector,
8 - 500V electric supply,
9 - radiation beam
10 - batteries,
11 - clock and radio transmitter,
12 - concrete base,
13- ground level

Design and analysis

Designing a dam, in view of the local conditions on the selected site, means first of all choosing the best suited type of structure: concrete dam, embankment dam, or a combination of both. This supposes that the exact location and height of the dam have been decided previously, since the choice of a type of structure is the decisive stage in designing.
Due to the prevailing configuration of the valleys they were faced with, French engineers throughout history have been led to practice their art mostly on dam sites in narrow valleys, and, more especially, as often as local geology allowed, on concrete dams. Nevertheless, wide valleys and embankment dams have not been neglected. In the past thirty years, their development has even been remarkable in various countries.
However, there never is a ready-made solution, as French engineers know very well. Thus, free of any dogmatic preformed opinion, they always endeavor to find the most suitable solution, from the point of view of project safety, economy and esthetics.

Concrete dams

For dams built in narrow valleys, we feel we should emphasize the project engineers' efforts to make the best use of available space. Close association of the various elements - dam, spillway, and powerhouse - is, at least a prominent economic factor, if not a simplifying one, especially when space is at a premium.
Thus were created the powerhouse-spillway-dams at l'Aigle, Bort and Chastang, on the Dordogne, with their external powerhouse at the heel of the structure, skijump spillway led along the downstream face of the gravity arch dam and over the roof of the powerhouse. Such concentration reached its peak at Monteynard (fig. 3-1, 1-7, 5-3) on the Drac; there, the powerhouse is inside the base of the arch dam, which shelters it from rockfalls.
The skijump spillways, invented by André Coyne, were largely responsible for the success of such complex works, for they increased the safety in regard to regressive erosion in flood water stilling pools, thereby allowing lightweight, elegant solutions to release the water over the powerhouses, in the axis of the valleys (fig. 3-2). Outside of France, the skijump spillway won acceptance very slowly. But today, it is acknowledged worldwide as a very advantageous solution.
If the valley is really too narrow to contain an external powerhouse, underground construction remains as a last resort; this is the solution chosen for the arch dam at Oymapinar, in Turkey (fig. 3-3).
In wide valleys, let us dwell on the way those valleys were harnessed by arch dams, and



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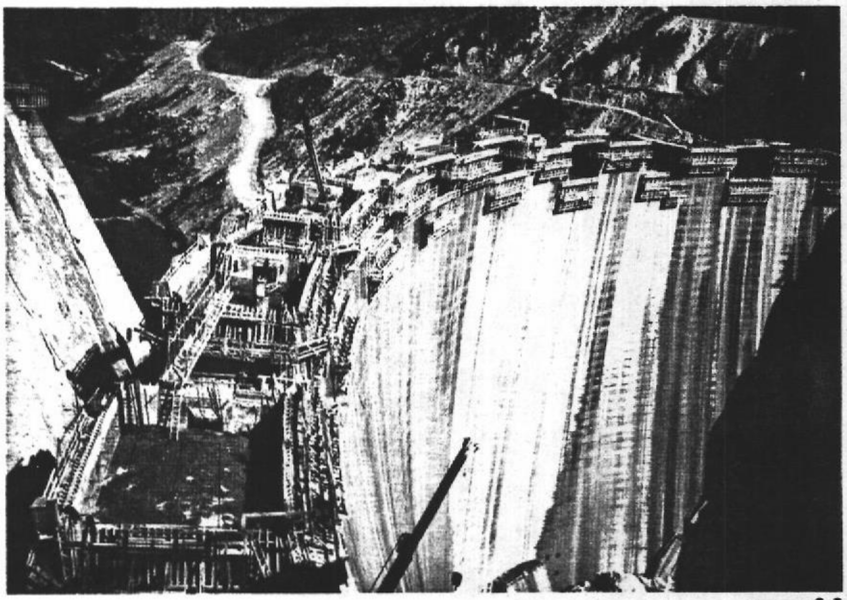
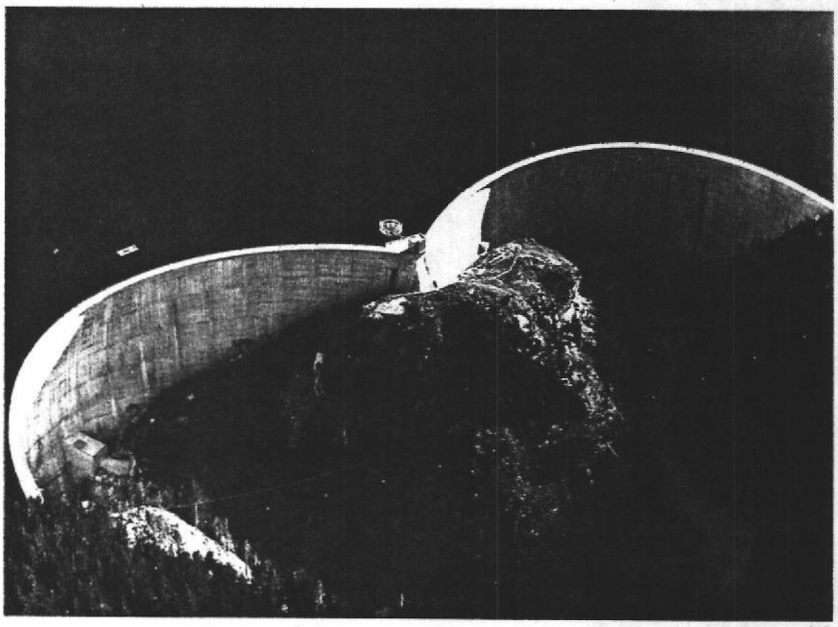


3-3

Foundation treatment

Treatment of a dam's foundations nowadays involves increasing use of special techniques: grouting, diaphragm walls, anchorages and rock anchors, wells and drains, dynamic consolidation of the soils.
The aim is to consolidate the foundation of the dam and associated structures, stabilize the slopes, insure watertightness of the reservoir, control uplift and leakage flows. It is also important to facilitate construction or repair and/or such modifications as raising of the dam.
Thanks to their inventiveness, French engineers have often led the way with breakthroughs in special techniques, such as high capacity rock anchors: A. Coyne in 1935; sleeve grouting: E. Ischy in 1950; plastic concrete diaphragm wall, in 1964 or cement grout diaphragm wall in 1970.

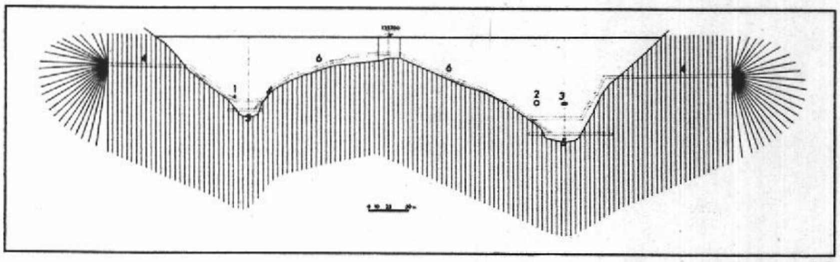


4-1

Grouting

GROUTING OF THE ROCK

This is the oldest of all special techniques. In its classical form, it allows making watertight the rock abutments of a dam-the wing cutoff -and consolidating the fragile rocks. The quantities of grout are rarely large inasmuch as a rock usually contains a small percentage of voids: approximately 1 to 3 %. The grout used is a suspension of cement in water, injected under pressure from simple holes. The French technique has shown (H. Cambefort) the advantage of high pressures to increase treatment efficiency.
Grouting of the rock may be a more complex operation, for example in the case of a karstic site, or where galleries are to be made.



4-1

GROUTING OF ALLUVIUM

This is now a classical technique, which the development of injection by "sleeve grouting" has made quite easy. The best known case of this technique being used is the cut off in the alluvium (grouting to 100 m in depth) under the dam of Serre-Ponçon (1952-1957). Large quantities of grout must be injected, for in alluvium the percentage of voids often exceeds 30 %. The main grout used is a mix of bentonite (or clay) and cement which is suitable to sands and gravels. For finer soils, silica gels are used. Preparing these mixes, controlling and grouting them under pressure is effected by automated plants; drilling and grouting are conducted separately. This makes it easy to adapt works management to difficult sites.
Monitoring of the first cutoffs in alluvium has been going on for more than 20 years now, and each passing year has confirmed their durability. Moreover, due to their very nature, grout cutoffs stand up very well to the movements of the subsoil when submitted to overloads.

Diaphragm walls

This concerns techniques that make possible the creation of a cutoff starting with a trench which is then filled with a flexible material, so that the cutoff may stand up, without cracking, to the thrusts exerted on the structure in which it is built.

Bentonite diaphragm wall - A trench, at least 1.5 m wide, is kept full of mud while it is being cut and filled, as it progresses, with the agregates from the excavation. This wall has the advantage of needing no cement, but the corollary drawback of lacking mechanical strength.

The thin diaphragm wall is called thus, due to its lack of thickness: 0.10 m approximately. It is built by driving in (often by vibrating) a metal section which is then extracted while a bentonite-cement grout is simultaneously injected at the bottom. This method is especially suitable when making watertight dykes and canals under low hydraulic load.

The plastic concrete diaphragm wall is perforated, like a common moulded wall, under bentonite mud. A pipe is used to replace the mud with concrete made flexible by adding bentonite and reducing the amount of cement and agregates. Usual thickness of such walls ranges between 0.60 and 1.20 m. This type of wall is widely used: it allows going down to great depths (100 m), through hard layers, or blocks smaller than the thickness of the trench, and enables resisting movements of the surrounding earth mass without cracking.

The grout diaphragm wall differs from the preceding one because the trench does not contain agregates, but only the same bentonite cement grout, which was used during cutting of the trench. Thus concrete placing is avoided, hence greater economy and perfect

Concrete dams

The many favorable sites to be found in France explain why masonry, then concrete dams have been built for such a long time. The Gouffre d'Enfer gravity dam, near St-Etienne, built in masonry, is 60 m high, a world record for the time (1866); the Zola dam (fig. 1-1), also built in masonry in 1854, was a considerably advanced arch for its time. Both these structures are still in use today.

The engineers' feats of imagination in striving to extract the most out of each site, technically as well as economically, joined to advances in hydraulics and materials, led to the construction, in France, of concrete dams of many different types. The important role played by French consultants and contractors in many foreign countries has made them capable of solving problems of the most varied kinds.

Their experience covers indifferently the following fields:

- the design of all types of concrete dams (gravity, thin or thick arches, domes, multiple arches, buttresses,...), spillways (classical types or skijumps, bottom or mid-level spillways, stilling pools), and associated works (aboveground, underground, or in-dam power plants);
- the completion of works under any conditions of climate, access or logistics;
- during the works, control of unpredictable, large-size rivers with the additional demand of continued navigation.

The following examples illustrate some of the unusual or particularly difficult construction characteristics among many concrete dams built in France or abroad, with the help of French consultants or contractors. The facilities mentioned deal with power production, irrigation, water supply or flood control.

ROSELEND BUTTRESS AND ARCH DAM (fig 5-1 and 3-5).

Operational in 1961, this composite structure is one of the most remarkable examples of adaptation to the topographical and geological conditions of the site: on the left bank, a narrow gorge is dammed by an arch truncated at the top; on the right bank, a rocky spur is heightened by a buttress dam, abutted on the arch where it touches the gorge. This meant savings of concrete of approximately 50% over a classical gravity dam.

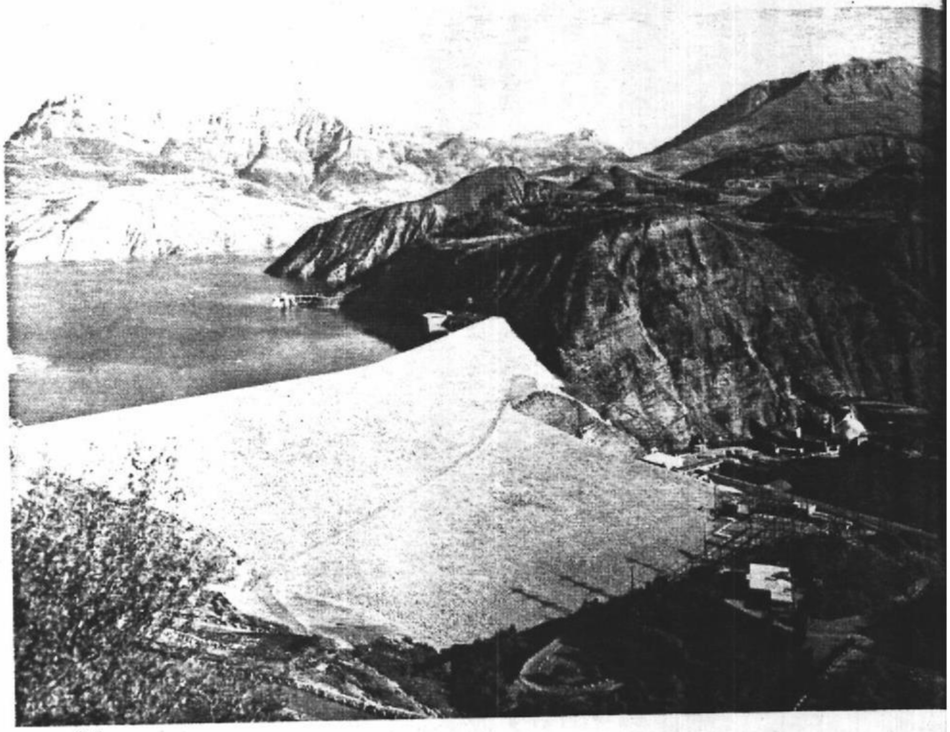
Besides the problems linked to the shape of the structures and the setting up of the cableways and concrete pouring crane on an extremely uneven site, building this structure at a high altitude was made difficult by the limited 6 months per year concrete-pouring period and the need to clear some 500 000 m^3 of snow each spring when the job site was reopened.

5-6

5-6
Karoun arch dam (Iran).
Height : 200 m;
crest length : 380 m;
volume of the dam : 1 200 000 m^3;
storage capacity : 2 900 million m^3.
Operational : 1975.

Embankment dams

The construction of earthfill embankments is the most common, and certainly the oldest method used by men, to channel and retain waters. Traces of this type of works - generally of low height - can be found in the remains of the oldest civilizations.
It is in the XVIIth century, and especially in France, that the construction of these structures, which had been empirical until then, began to be founded on more rational, and already almost scientific reasoning.
Thus the first real dam was built, between 1666 and 1675 at Saint-Ferréol, in south-west France, by engineer Riquet, as part of the works for the Canal du Midi. It is an earth dam 36 m in height, with a masonry core. This structure, which is still in operation today, bears witness to the know-how of its builders.
About one century later, again in France, during works to develop inland navigation, theoretical research was started for the first time on the behavior of materials and the flow of water in the soils. The studies of Coulomb, in the XVIIIth century, then of Collin and Darcy, around 1850, set the foundations for the spectacular development of soils mechanics in the XXth century.
This favorable context led the French builders very early to combine successfully the ancestral practices of earthworks with the exacting demands of sophisticated structures. Therefore, French contractors were quite naturally prepared to exploit fully the downright revolutionary change caused by the introduction of modern, powerful equipment after World War II; this placed them in the best position to tackle the construction of the largest embankment dams, whose development could thus benefit from contemporary progress in soil mechanics.
The achievements of French firms have grown in number since, first in France, then very quickly on every continent.
In France, the vast hydroelectric program started after the second world war. Then the recent development of facilities for energy tranfer by pumping have called for the construction of many dams, among which is an increasing percentage of embankment dams. This percentage is nowadays 60 to 70% of the dams starting operation each year. This amounts to a wide range of structures - from the homogeneous dam, with or without impervious facing, to the zoned dam in earth- or rock-fill with an impervious zone - which French firms have had to build in the past thirty years.
These usually important works (see below), have led to perfecting safe, modern, often original methods resulting in lower costs and shorter construction times.
Thanks to the experience acquired in this way within their borders, French firms quickly achieved world standing on international markets. The large works conducted suc-



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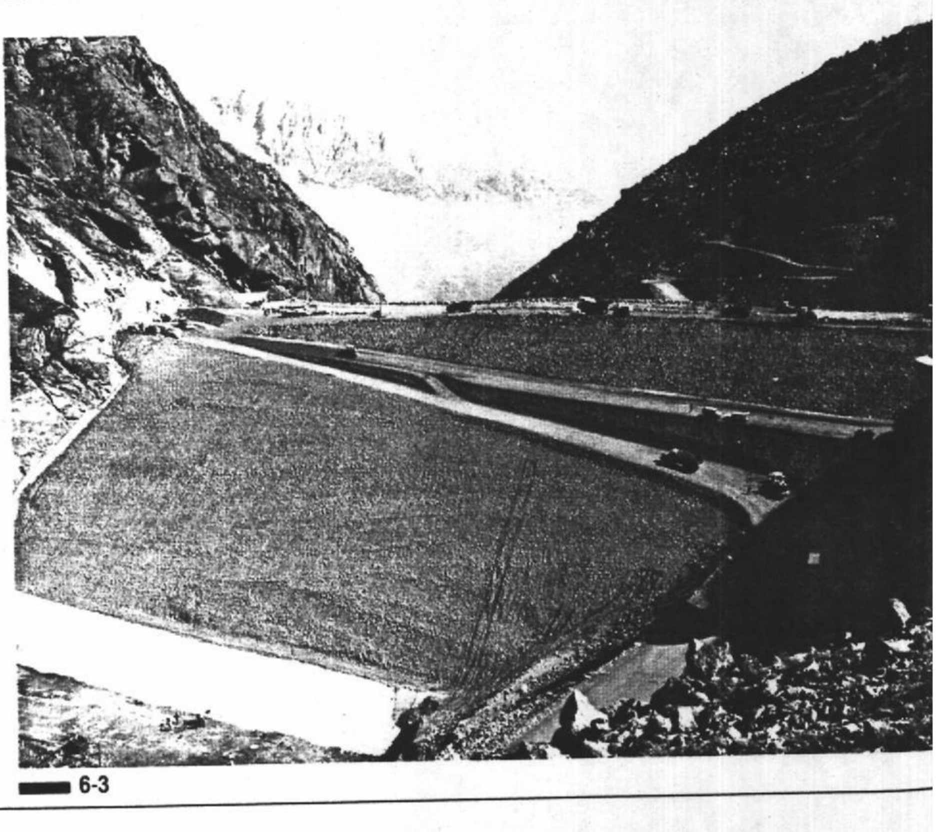


6-3

Ancillary works

A dam requires a certain number of works which are necessary to its safety. These are spillways and bottom outlets capable of performing essential hydraulic functions, in particular:

- spilling of flood water,
- control of the water level in the reservoir and of its silting by sediments.

In many cases, other functions will have to be performed by works associated with the dam:

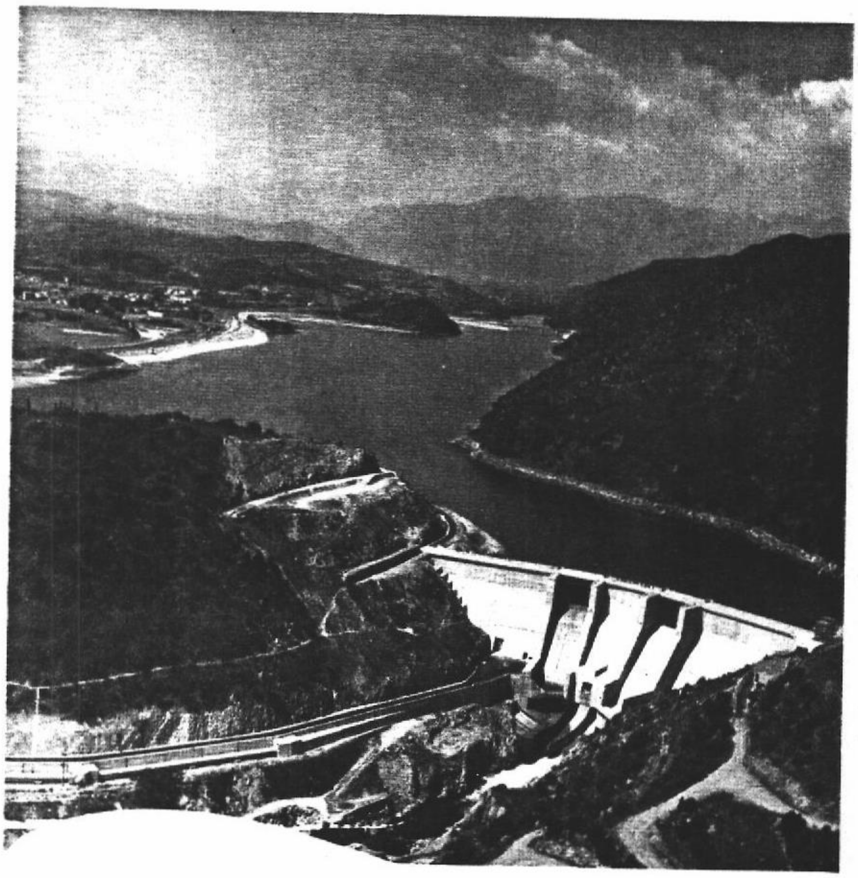
- passage of the fish between the reservoir and the river, via a fish ladder, fish locks or fish lifts;
- continued navigation through one or several locks, boat lift or water slope;
- foundation works in the channel of the river and protection of the works during construction, requiring a temporary diversion.

French engineers have found a way to apply the best of their creative imagination to the design of these works; they have sought to integrate them to the body of the dam, or to associate them to it in an effort to keep down costs. Such works do not deserve the name of "ancillary works" anymore, since they then form an intimate part of the dam structure itself. There are some cases even, when the design of these hydraulic works will guide the engineer's choice for the type of dam structure best suited to the available site.
Beside the spillways called "skijump spillways", French manufacturers of hydraulic equipment have also adapted the radial gate to close bottom outlets, in order to control the discharge flows, the first filling of the reservoir, and silting; this has considerably improved safety.
On a large number of sites, use of the temporary derivations is not limited to the period of construction. Subsequently, they also serve as tunnels for the bottom outlets or the intakes of the associated hydro-electric power plant. On the site of Serre-Ponçon, it has been possible to combine these three functions.
The successful design of these hydraulic works requires analysis on scale models to which the criteria of hydraulic similitude are applied. In this field, which it pioneered, France has continued to perfect the existing techniques, simulating increasingly complex phenomena. It is in French hydraulic laboratories that all the studies for the large national, as well as many foreign, structures were conducted; it is there also that certain processes were tested, that have furthered the state of the art in hydraulic works:

- diversion of a river with loose material,
- discharging of suspended sediments by density currents,
- flow-deflecting devices (chute blocks, deflector buckets,...) on the spillways (fig. 7-1, 7-2),
- energy dissipators and protective devices against cavitation in high velocity flows,
- erosion control downstream of the structures,
- stability of overflow embankment dams,
- resistance of slopes to wave action.

Spillways and bottom outlets

One should distinguish the spillways which discharge the excess flow entering the reservoir, at an elevation close to its maximum level, from the mid-level or bottom outlets, which open at a considerably lower level.



7-1

7-2

7-1
Vinça gravity dam, on the Têt river.
Height : 60 m;
crest length : 190 m;
volume of the dam : 140 000 m^3;
storage capacity : 24.6 million m^3.
Operational : 1977.
The two spillways have a discharge flow of 1 500 m^3/s.

7-2
Vinça Dam; spillways study on a scale model.

Supply works

The supply works :
- diversion channels,
- headrace tunnel,
- penstock,

provide the hydraulic connections between the dam and the other work of the scheme. Those supply works of various types call for specific techniques of execution, which have been widely used in France in the past four decades, within the hydro-electric program of the country and abroad, by French consultants and contractors.

Diversion channels

When allowed by site topography, open air collecting works, by channel, can be integrated to the various schemes of hydraulic equipment in mountains or in plains. Moreover, in the alluvial plains of the larger rivers, such diversions, which are always spectacular, also act as navigation canals.
The progress in modern earth moving techniques has given renewed impetus to those canals whose main characteristics are given, for a few of them, in the table of figure 8-1.
The CNR (Compagnie Nationale du Rhône) has been assigned the task of equiping the Rhône for energy production, navigation and agricultural use (8.2). This development is being completed upstream of Lyons. Between the reservoir of Génissiat and the Mediterranean, the remodeling of the valley includes 215 km of open diversion. As of now, the Rhône, extended by the Saône, makes up a modern 500 km waterway which the projected Saône-Rhine linking (229 km) will connect to the European large

8-2

8-1
Synoptic table of the main characteristics of some French diversion canals.

8-2
Caderousse scheme, on the lower Rhône; general view of the dam-lock (5000 t units) -powerhouse (156 MW-860 GWh).

Development	Donzère Mondragon	Ottmarsheim	Rhinau	St Estève	Sisteron	Salignac	Golfech	Echaillon	Belley
River	Bas-Rhône	Rhin	Rhin	Basse Durance	Moyenne Durance	Moyenne Durance	Garonne	Arc	Ht Rhône
Dam Owner	C.N.R.	E.D.F.	E.D.F.	E.D.F.	E.D.F.	E.D.F.	E.D.F.	E.D.F.	C.N.R.
Design flow (m^3/s)	1800	1160	1400	265	245	320	650	85	700
First operational	1952	1952	1964	1962	1975	1977	1973	1974	1982
Installed capacity (MW)	348	170	151	140	228	82	69	111,5	90
Yearly output (GMW)	2110	980	940	675	649	220	312	373	455
Length of canal (km)	17 (+11)*	15	12	27,5	32	4,6	10,6 (+2)*	2,4	13,5 (+1,6)*
Bottom width (m)	83	80	100	8,6	8,6	15	59	6	18 fill
Water surface width (m)	145	136	155	42	41	48	101	34	84 fill
Draught (m)	10,3	9,4	11	8,3	8	9	10,5	7	11
Incline of slopes	3/1	3/1	2,5/1	2/1	2/1	2/1	2/1	2/1	3/1
Volume of fill (10^6 m^3)	40	19,5	12	33	11	2	5,2	1	10
Lining	slab and alluvium	concrete	concrete on the banks	concrete and slabs	bituminous concrete	bituminous concrete	bituminous concrete and rockfill*	concrete and pitch vinyl	quarry materials
Total length of diversion channels in the valley (km)	213	97	97	176	176	176	30	2,4	47

* tailrace canals

8-1

Hydro-electric plants

General design of hydro-electric plants

The mission of the designer of a hydro-electric powerstation is to create a plant that is exclusively functional, but which does not preclude esthetic considerations.
The progress of the techniques, together with the increasing power of the units, and the resulting decrease in their numbers, the development of automation and remote control, as well as the creation of centralised control stations,... have made possible highly functional plants.
Drawing on the available experience, the designer can introduce lightening and simplifying measures, such as:

- reduction in the number of levels and floors,
- concentration of instrument panels and auxilliaries,
- reduction of distance between units,
- selection of the most direct paths, in particular for overhauling operations and parts handling.

Hydro-electric plants can be classified in two main categories:

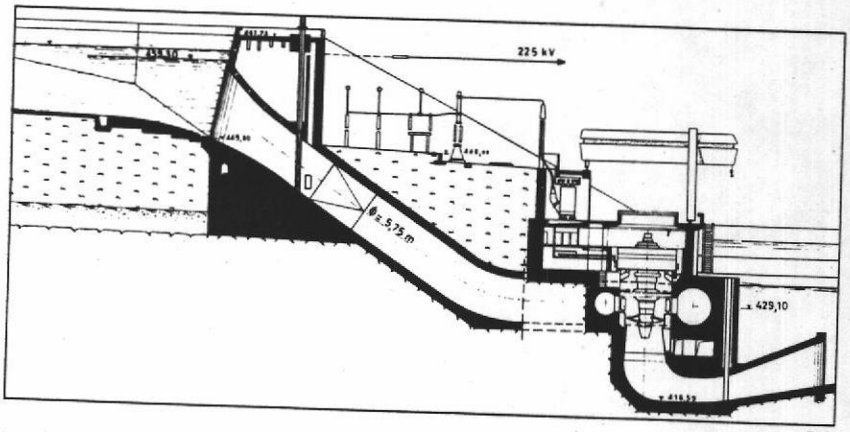
- above ground power stations,
- underground or shaft power stations.

ABOVE GROUND POWER STATIONS

Above ground power stations may make use of many variations of the "classical building". The use of prefabricated elements, of metal frames, the simplification of formworks and roof structures, now allow sizeable savings in the construction of a plant. Simplification may even go to the selection of the "outdoor" plant, where building superstructures is dispensed with, each unit being covered by a watertight cover, and the overhead travelling cranes replaced by travelling gantries (fig. 9-1).
In the case of a low head scheme, the plant building itself may be eliminated; each unit, consising of a horizontal flow, axial turbine and an alternator, is located in the cell created between the buttresses of the dam, the upstream face and the spillway (9-2).

UNDERGROUND OR SHAFT POWER STATIONS

Starting in the 70's, most French hydro-electric plants built in the mountains are underground, a solution dictated by the cramped site, the nature of the soils, savings made on the hydraulic circuit, environmental protection,...
With the pump storage plants, underground location is almost the rule, since it is imperative that a head in the order of 25 to 40 m



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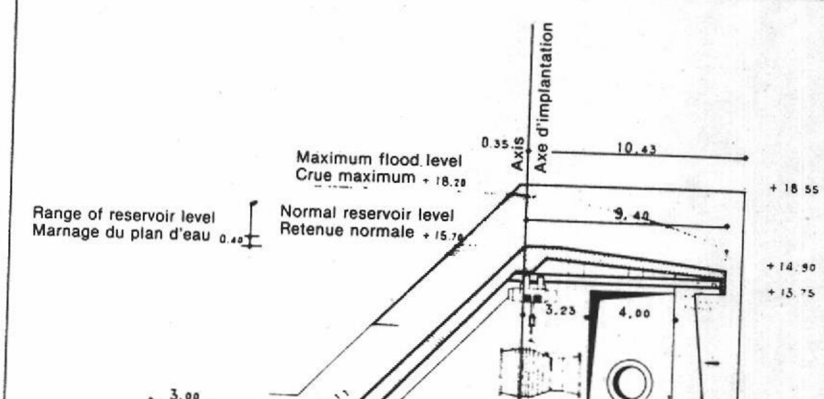


9-2

9-1 Salignac "outdoor" powerstation (2 x 43 MW); cross-section of the plant.

9-2 "Maulde" type power station; cross-section.

Surveillance of dams

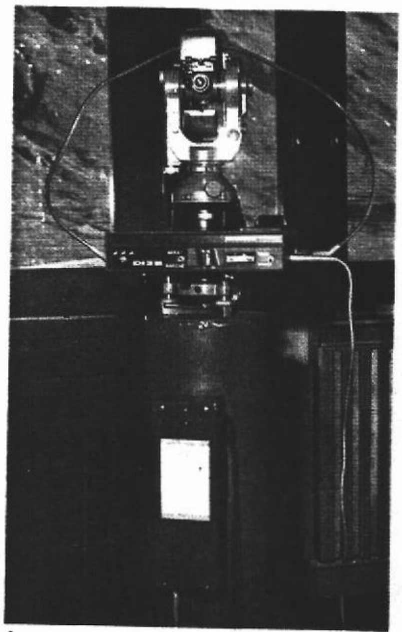
Monitoring a dam comprises all the operations pertaining to measuring with maximum precision the various parameters capable of representing, at the time selected, the behaviour of the dam taken as a whole - dam and foundation - or in part.
Surveillance seeks to meet two requirements:

- control of the safety of the dam as regards deterioration and failure, so that the works necessary to dam maintenance and safety be undertaken in time;
- analysis of the behaviour of the dam, to acquire knowledge useful in the design and calculation of future works.

France has accumulated considerable experience in the monitoring of dams, which it has been conducting for several decades. One should mention, in particular, the important role played in this field by Electricité de France. The choice of the measuring instruments and methods best suited to the various types of dams, the development of methods of analysis and interpretation of the measurements, as well as the organisation selected by EDF, can guarantee the efficient and homogeneous surveillance of some 150 dams operated by this national Service. An organization such as this one is often chosen for a model by many foreign countries.
French manufacturers of measuring instruments can offer a wide range of instruments which meet perfectly the requirements listed below.

Fundamentals of dam monitoring

Dams are long-lived works; therefore, monitoring instruments are required that will be **reliable** over comparable periods, in order to limit the consequences of incidents likely to affect the works during their operational life.
Monitoring applies to small amplitude phenomena, with the desire to detect, early enough, discontinuities, significant changes indicating malfunctions; it must therefore make use of very **sensitive** instruments.
Simple and fast means allow continuous control of the behaviour of the works, the measurements being made by the local staff, without resorting to specialists.
A fundamental evolution has taken place during the past decades, with the increasing importance assigned to surveillance of the foundations in the field of deformations and hydraulic behaviour.
Visual surveillance of the dam and its surroundings, done by experienced persons, cannot be replaced.
The first filling of the reservoir of a dam is an important and delicate phase in the life of the works. It is, in fact, a test which permits judging if the dam is capable of accomplishing its mission. This phase of the surveillance requires, on the site, the presence of competent staff, capable of interpreting correctly and quickly the results of the measurements.



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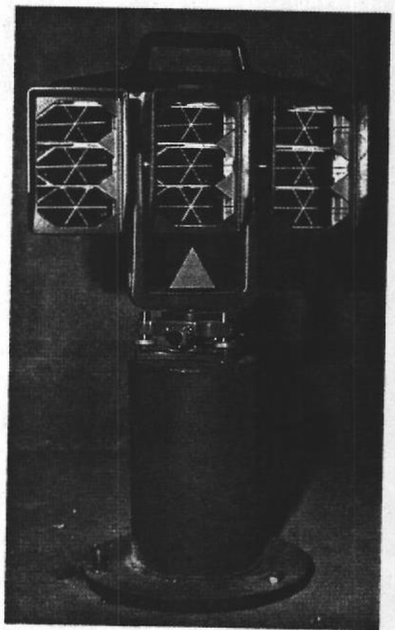

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Monitoring instruments and methods

The study of various control criteria according to the type of dam leads to specific measurements using special instruments.
Concrete dams - Measurements of absolute or relative movements can be made with:

- topographical instruments: theodolite (for triangulation); electro-optical distance measuring instruments (trilateration - fig. 10-1 A and B); levelling instrument and invar levelling staffs (precision levelling).

Computer processing of the calculations has considerably improved the speed of result acquisition, while providing additional means of assessing their quality;

- pendulums: "sight points" type; telependulum (remote transmission of measurements - fig. 10-2);
- measurements of rotations: clinometers;
- measurements on joints and cracks: three dimensional joint gauge or crack opening submersible telemeters;
- measurements of strains: vibrating wire extensometer (fig. 10-3) with recording of measurements.

Other types of measurements:

- measurements of concrete temperature: thermocouples, vibrating wire sensors, resistance sensors;
- measurements of forces: dynamometers;
- measurements of leakage flows - fig. 10-4: capacitive devices, flow gauging weirs.

Embankment dams - The measurements of external absolute or relative movements can be made with the following methods and instruments:

- Topographical measurements by: triangulation, trilateration, levelling, photogrammetry (considerable progress has been made on photographic instruments and treatment methods.)

Measurements of internal relative movements use instruments such as:

- hydrostatic levelling, electromagnetic and hydraulic settlement meters;

10-1
Monitoring of the movement of a point on a versant by distance-measuring with a fixed electro-optical device.
A. Infrared distancemeter installed at the survey station on a fixed theodolite aimed at the point to be monitored.
B. Reflector at monitoring point, in a shelter aproximately 2 000 m from the survey station, which is supposed to be fixed.

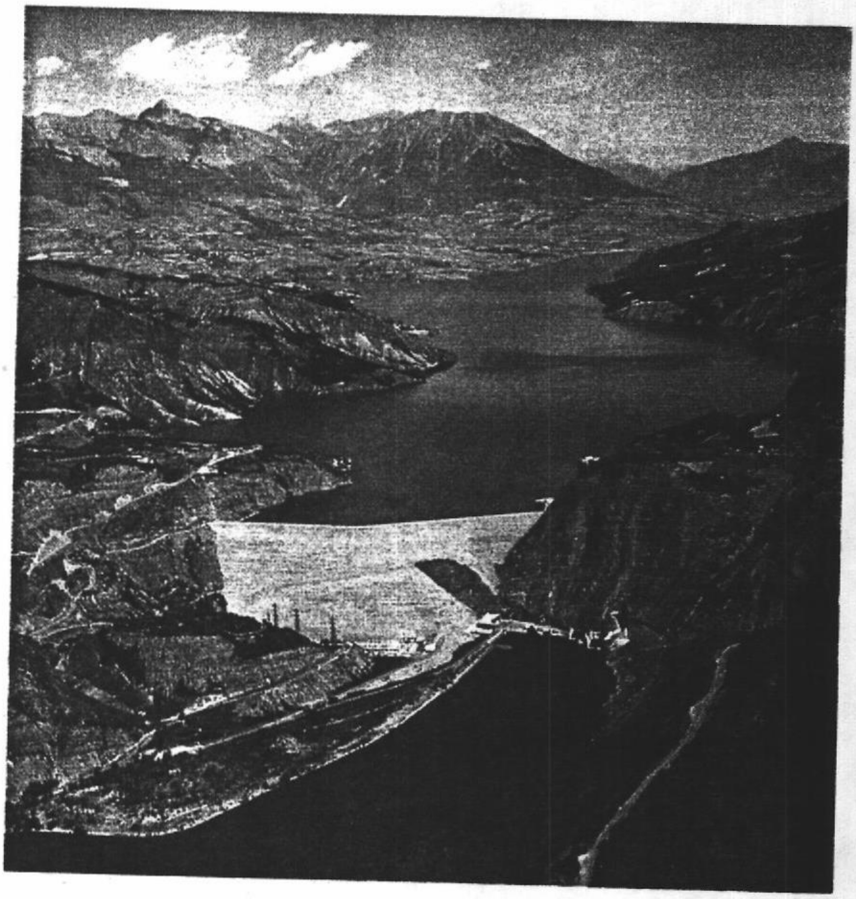
Dams and environment

Hydraulic developments, due to their dams and their reservoirs, leave important marks on the landscape. They cause effects on the regimes of the aquifers, on the water and solid materials flow in the rivers. If no precautions were taken, these could bring about biological consequences, at times of unforeseen importance.

The economic or social aims of the developments (energy, waterways, leisure, water supply for domestic, industrial or irrigation purposes, regulation) all have an influence around the streams and reservoirs, or even further, due to the transportation of water or energy. These consequences are generally very beneficial. But apart from the immediate, visible or foreseeable repercussions, the long term effects, which are often concealed or impossible to foresee, should be watched closely.France, with a very extensive program of hydraulic and energy-producing developments realized in the past decades, has been especially careful in the field of environmental protection. Precise legislative measures have been taken to insure effective conservation of the water resources (1964) and the natural environment (in 1976). Government bodies and organizations, urged in fact by Various environmental asssociations, have made sure that the development planners were taking precautions which might have seemed needless or superfluous in the past. The environmental impact study, which is now required of the dam owners, makes it possible to draw an inventory of the problems that need to be studied further, and of the solutions to be implemented. These concern the physical environment (land and waters), the ecosystem with its fauna and flora as well as man and his various activities.

Effects on the land and waters

Natural rivers result from a balance, reached over thousands of years, between the land and the waters. The presence of a dam, the development of a stream, cause an inevitable unbalance in an equilibrium that is sometimes fragile : in certain, unfavorable circumstances, the profiles of the river can be upset or modified, and the channel can become the scene of landslides, erosions and deposits.



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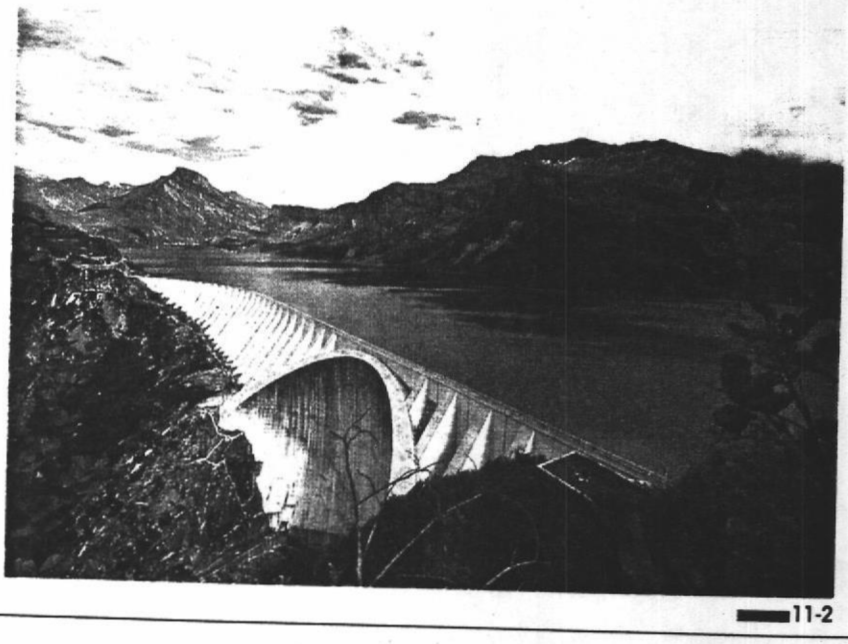

11-2

11-1 Serre-Ponçon earth dam.

11-2 Roselend dam.

Training technicians

The problems posed by dams, at all stages from design to operation, fall within the domain of many scientific fields, on every level from the design engineer to the unskilled worker, including the many specialists who, from the engineering department to the laboratory, from the manufacturing plant to the construction site, contribute to the realization of the works.
Theoretical knowledge must be bolstered by substantial experience, which can be acquired only through practice and contact with experts of long standing, in the framework of specific training sessions.
The experience acquired in France as well as in foreign countries by the consultants, contractors and engineers, has led, in this country, to the creation of a large number of educational establishments which can provide the firms in charge of project execution with the skilled personnel they need.

Basic training

Basic training is offered in the schools of higher technical education, whose syllabuses include the fundamental elements of civil engineering and, more precisely, those dealing with dams :

- Ecole Nationale des Ponts et Chaussées (founded in 1750), whose syllabuses have evolved gradually to meet the demands of modern industry, especially in the field of civil engineering and dams;
- Ecole Nationale du Génie Rural, des Eaux et des Forêts, which teaches hydraulics and soil mechanics used in dam design; the option "water control and devlopment" deals with subjects used in agricultural hydraulic projects;
- Ecole Nationale Supérieure d'Hydraulique de Grenoble, and especially its options "Hydraulic Engineering for Works" and "Water resources and developments";
- Ecole Nationale Supérieure d'Electrotechnique, d'Electronique , d'Informatique et d'Hydraulique de Toulouse, Hydraulics Department;

The last three establishments devote a large part of their syllabuses to the basic techniques used in dams, in the field of hydrology and hydraulics as well as those of soil and foundations mechanics, and resistance of structures.
Other schools for basic training in civil engineering offer options in hydrology and hydraulics, which enables them to deal with most, if not all the problems encountered in dams. Among the schools of this type:

- Ecole Nationale des Travaux Publics de l'Etat in Lyons;
- Ecole Nationale des Travaux Ruraux et des Techniques Sanitaires in Strasbourg;
- the Instituts nationaux des Sciences appliquées in Lyons, Toulouse and Rennes, which train civil engineers.

All these establishments of higher learning admit engineers holding a French or foreign degree, according to each school's requirements. They can also enable graduate engineers to further their training in a more specialized field, by registering at the "Research and Development" level, to acquire a Diplôme d'Etudes Approfondies (DEA) or a degree of Ingénieur-Docteur.
Among these types of training, beside those in the schools already cited, one should mention the specialization course in soil mechanics of Ecole Centrale des Arts et Manufactures de Paris, which devotes part of its syllabuses to earth dams and dam foundations.

Continuing training

The aim of continuing training is essentially to update the engineers' initial training, by taking into account the most recent acquisitions of the science and techniques of application. It is conducted in the form of seminars or "study days", of limited duration, which make it possible to present the new methods developed by research, and directed toward practical use.
In the field of large dams, this training is given more particularly during special sessions, organized by the following institutions:

- Ecole Nationale des Ponts et Chaussées,
- Ecole Nationale du Génie Rural, des Eaux et des Forêts,
- INSA in Lyons,
- Ecole Nationale des Travaux Publics de l'Etat,
- Ecole Nationale des Ingénieurs des Travaux Ruraux et des Techniques Sanitaires,
- Centre Expérimental de Recherche et d'Etudes du Bâtiment et des Travaux Publics.

These Institutions regularly organize sessions of continuing training, lasting one or two weeks, dealing with the techniques used in the field of dams: soil mechanics, rock mechanics, execution of works and structures at ground level, geotechnic analysis and control of earth works, improvement and reinforcing of the soils, use of geotextiles, earthfill dams,...

Sessions of applied training

The sessions of applied training aim at making the engineers and technicians conversant with a particular field of dam technique (problems in the execution, methods of analysis of the works), at the level of everyday applications and "trade know-how". The corresponding knowledge can be acquired only during study sessions of varying duration, in Institutions specialized in the analysis and construction of dams : owners, consultants, contractors, equipment manufacturers dealing in the relevant fields. Such sessions play a very important role in the training of personnel (engineers, technicians, contractors agents, skilled workers) and are often organized to coincide with the realization of a works, so that several members on the owner's staff may acquire the technical knowledge necessary for the works operation.
Among the different forms these sessions may take, one can mention the following:

- **Sessions organized by Electricité de France (E.D.F.),** which welcome 600 to 800 foreign engineers and technicians each year, for periods of a few days to a few months, in the form of :
- sessions of training and further education, comparable to the sessions offered to the personnel of E.D.F.; the syllabus is chosen in collaboration with the foreign organization to insure maximum efficiency, and consists in courses on theory, stays in E.D.F. Departments, completed by stays in the plant manufacturer firms. If E.D.F. has been charged with conducting a specific study, the executives of the "client" company may be asked to share in the design of the projects.
- Sessions of information, for already experienced engineers, wishing to learn what methods are being used by E.D.F. in construction, or optimum management of its works or equipment.

These sessions may last a few weeks and include talks, visits and seminars. For instance, each year in October, a session called: "Techniques and measurements on hydraulic works", is organized at the "Division Technique Générale" (DTG), in Grenoble. The engineers of the DTG share their experience in the various fields of activity of this Service, particularly in dam monitoring.

- **Sessions organized by the CEMAGREF** (Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts) on the subject of hydraulic works : soil mechanics, hydraulics, hydrology, geotextiles, geomembranes,...
- **Sessions organized by the Laboratoire Central des Ponts et Chaussées,** which, after examining the files of applicants, welcomes foreign students in the following fields : geology, soil mechanics, rock mechanics, materials, foundations, reinforced concrete,...
- **Sessions organized by the Laboratoire d'Hydraulique de l'ENSEIH** (Ecole Nationale Supérieure d'Electrotechnique, d'Electronique, d'Informatique et d'Hydraulique) in Toulouse, on the techniques of hydraulic models, which are one of the specialities of this laboratory.

Last, but not least, comes the delicate training of the engineers whose ultimate responsibility it will be to lead the design and construction of the dams : the "specialists of synthesis". The solution to the problem posed by