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## **UPGRADING THE MAIGRAUGE DAM (\*)**

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### 1. INTRODUCTION

The Oelberg-Maigrauge scheme, located at 550 m a.s.l. close to the city of Fribourg, is part of a power plant cascade on the Sarine River, owned and operated by the "Groupe e SA".

The Maigrauge dam, designed by Guillaume Ritter, is the oldest concrete dam in Europe. Completed in 1872, the plant was the masterpiece of an important industrial development program of the city of Fribourg.

The dam was designed as a concrete gravity dam and built using aggregates from the Sarine River in the vicinity of the dam site. It is a 21 m high and 120 m long structure with neither vertical contraction joints nor drainage system. The crest of the dam describes, in plan, a curve prolonged by a straight section on the left bank. The thickness of the structure is 6 m at the crest and 26 m at the base.

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(\*) *Réhabilitation du barrage de la Maigrauge*

The volume of concrete used for its construction is about 32'000 m<sup>3</sup>. The dam is founded on relatively compact and homogeneous sandstone characterized by a sub-horizontal bedding. The gross storage capacity of the reservoir was initially of 1.0 hm<sup>3</sup> while the total catchment area of the Sarine River at the dam site is 1'290 km<sup>2</sup>.

The spillway, located on the left bank, was entirely excavated in sandstone. It consisted of a 30 m wide free overflow sill discharging into a short canal ending with a 10 m high sill. The latter diverted the flow into the tailrace scour basin excavated by the spillway operation.

The dam was also equipped with a bottom outlet for sediment flushing. However, the conduit was rapidly clogged by sediments and debris and after a few years the outlet work could no longer be operated and was partially plugged with concrete. The loss of the bottom outlet was mainly attributed to negligence of the dam owner and in particular to important delays in flushing the sediments in the reservoir.

The powerhouse, located on the right dam abutment, was initially equipped with two turbines of 300 HP each: the first one was connected to a pump to supply water under pressure while the second provided mechanical power to the nearby industry by a dynamic cable system. In 1895 the powerhouse and its equipments were replaced to generate electricity.

Between 1909 - 1910 the crest of the dam was heightened by 2.75 m up to elevation 552.90 m a.s.l. and prolonged by a 40 cm high wall at its upstream face. Heightening of the dam was probably due to the rapid sediment deposits in the reservoir. In the same period, the Oelberg powerhouse was built and the spillway on the left bank was equipped with four 7.25 m wide, 4.55 high radial gates.

From the intake structure, the flow is diverted by a 280 m long headrace tunnel to the surge tank, and from this through three 30 m long penstocks to the above ground powerhouse, which had an installed discharge of 33 m<sup>3</sup>/s and was equipped with 3 units of 1.85 MW Francis turbines operating under a gross head of 20 m.

The spillway on the left bank had a total capacity of 465 m<sup>3</sup>/s. The spillway gates have been operated throughout 60 years. With regard to discharge capacity of the dam it can be mentioned that overtopping of the dam was allowed to pass major floods.

In 1941 the scheme was completed with a second water intake and a new headrace tunnel. The powerhouse was extended and equipped with another 5.5 MW Kaplan unit, increasing the nominal flow capacity to 66 m<sup>3</sup>/s. Furthermore, the discharge capacity of the dam was increased by the installation of three sluice gates on its right abutment to flush out the sediments trapped within

the reservoir close to the water intake. The total discharge capacity of these 3 sluice gates was 180 m<sup>3</sup>/s.

The electro-mechanical equipments of the plant were successively upgraded including the installation of an additional unit in 1956 and the replacement of three units in 1980. The powerhouse is actually fitted with three Francis units and two Kaplan units with a total installed capacity of 17 MW and a total design discharge of 99 m<sup>3</sup>/s. The average annual power generation of the plant is 52 GWh, including the generation of the additional Kaplan unit (4 m<sup>3</sup>/s) installed in the ancient powerhouse and supplying the river meander with a minimum natural flow.

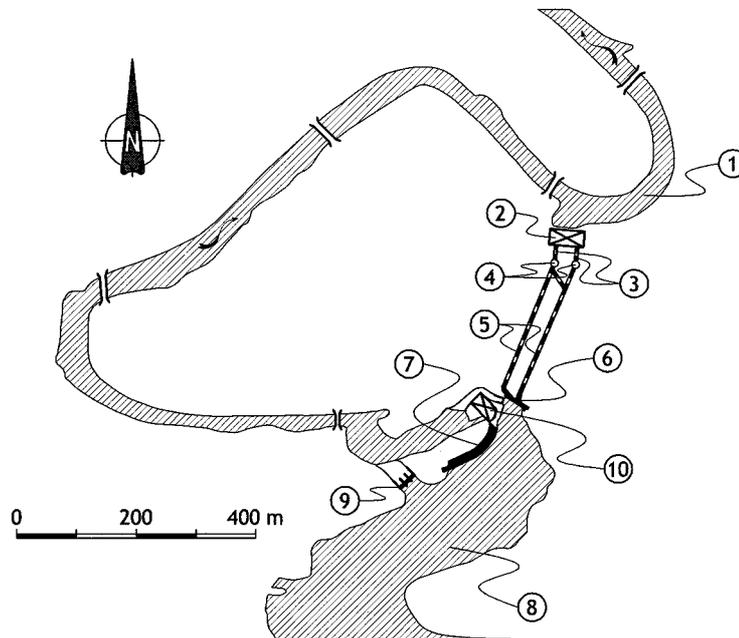


Fig. 1

General layout of the Oelberg-Maigrage scheme prior to rehabilitation works started in September 2000

*Schéma de l'aménagement de l'Oelberg-Maigrage avant les travaux de réhabilitation débutés en septembre 2000*

- |                        |                                  |
|------------------------|----------------------------------|
| 1. Sarine River        | 1. <i>Rivière Sarine</i>         |
| 2. Oelberg powerhouse  | 2. <i>Centrale de l'Oelberg</i>  |
| 3. Penstocks           | 3. <i>Conduites forcées</i>      |
| 4. Surge tanks         | 4. <i>Chambres d'équilibre</i>   |
| 5. Headrace tunnels    | 5. <i>Galeries d'aménée</i>      |
| 6. Intake              | 6. <i>Prise d'eau</i>            |
| 7. Maigrage Dam        | 7. <i>Barrage de la Maigrage</i> |
| 8. Péroilles Lake      | 8. <i>Lac de Péroilles</i>       |
| 9. Spillway            | 9. <i>Evacuateur de crue</i>     |
| 10. Ancient powerhouse | 10. <i>Ancienne centrale</i>     |

The reservoir is actually completely filled with sediments and the plant is operated as a run-of-river scheme with variations of water level between el.

552.70 m a.s.l. and el. 553.20 m a.s.l. The reservoir area is a protected natural zone, which means the reservoir can not be drawdown. The general layout of the dam and its appurtenant structures, as configured prior to the rehabilitation works, is schematically shown in "Fig. 1".

## 2. OVERVIEW OF THE PROJECT

### 2.1 FOREWORD

Although the behaviour of the Maigrage dam had been satisfactory for more than 130 years, upgrading works have become necessary to adapt the dam and its appurtenant structures to present safety standards. The spillway capacity was not sufficient to cope with the new hydraulic and hydrological safety requirements while the dam was deficient in meeting stability criteria in accordance with present standards, in particular under flood and seismic loadings. Furthermore, the intake structures suffered damages due to ageing phenomena; they were also equipped with out-of-date operating devices.

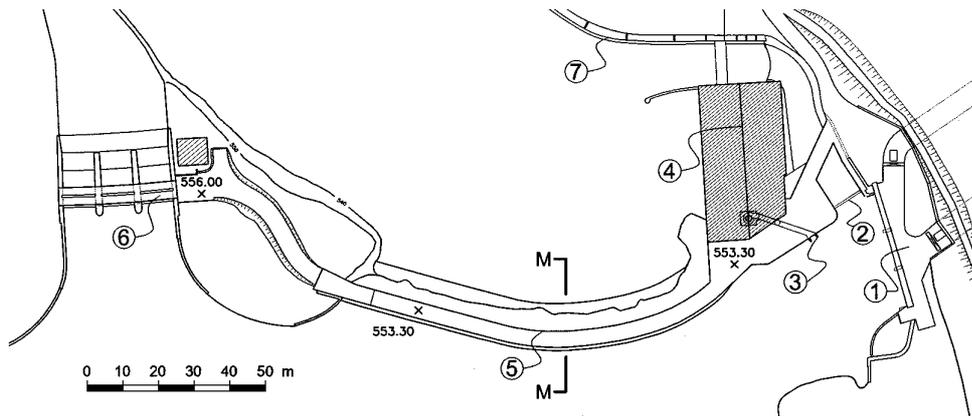


Fig. 2

General layout of the Maigrage dam and appurtenant structures after rehabilitation works completed at the beginning of 2004

*Représentation générale du barrage de la Maigrage et de ses ouvrages annexes après les travaux de réhabilitation achevés au début de l'année 2004*

- |                                 |  |
|---------------------------------|--|
| 1. Intake                       | 1. <i>Prise d'eau</i>                            |
| 2. Auxiliary gate               | 2. <i>Vanne de sécurité</i>                      |
| 3. Intake for compensation flow | 3. <i>Prise de dotation</i>                      |
| 4. Ancient powerhouse           | 4. <i>Ancienne usine</i>                         |
| 5. Gravity dam                  | 5. <i>Barrage poids</i>                          |
| 6. Main spillway                | 6. <i>Evacuateur de crue principal</i>           |
| 7. Fish pass                    | 7. <i>Ouvrage de migration pour les poissons</i> |

The general layout of the dam and its appurtenant structures, as configured after the rehabilitation works completed at the beginning of 2004, is shown in "Fig. 2".

## 2.2 FLOODS SAFETY

Constant evolution of dam safety requirements in case of floods associated with the need to ensure structural safety of the old weirs had justified upgrading and rehabilitation of the Maigrage spillways.

In this context it is worth mentioning that the construction of Rossens dam at the end of the 1940's, located on the Sarine River a few kilometres upstream the Maigrage dam, has also strongly affected the peak flood discharges at the Maigrage site.

In accordance with Swiss standards, the rehabilitated spillways of Maigrage dam had to be designed to pass the 1'000 year return period flood of  $850 \text{ m}^3/\text{s}$  assuming that the largest capacity outlet gate cannot be operated (n-1 rule), whereas the total required capacity to discharge the full "safety" flood, avoiding any dam overtopping, is  $1'190 \text{ m}^3/\text{s}$ . The latter takes into account a rapid drawdown of the Rossens' reservoir.

The total capacity of the existing spillways had to be increased significantly to match actual flood safety requirements. The evaluation of various alternatives finally led to increasing the capacity of the left bank spillway and building an auxiliary spillway on the right bank close to the intake structure, which will be operated only under exceptional flood conditions.

## 2.3 STRUCTURAL SAFETY

Dam safety assessment has led to the conclusion that the dam was deficient in meeting stability and strength criteria under severe flood and earthquake loadings. In order to adapt the dam to modern standards, strengthening measures became necessary. Different alternatives for the rehabilitation were analysed and compared with regard to technical, economical and environmental aspects. The final design consisted in the installation of 52 inclined pre-stressed  $1'600 \text{ kN}$  anchors drilled from the dam crest into the rock foundation (VIRET 2003 et al.).

Works included demolition and rebuilding of the dam crest, with concreting of a reinforced head beam to distribute the anchor load, and drilling of pressure relief drains from the downstream toe of the dam. The monitoring system of the dam was also upgraded and extended with the installation of an inverted pendulum.

## 2.4 ENHANCE OF OPERATING CONDITIONS

Besides safety concerns and durability of the structures, the project aimed also to improve overall operating conditions of the plant and in particular of the water intakes. The two more than 60 year old intake structures were affected by ageing effects and their electromechanical operating devices needed to be replaced.

The two existing structures were demolished and replaced by a single intake weir, which feeds the two headrace tunnels. The 32 m long weir is equipped with a fully automated trashrack rake.

Operating conditions of the intake have also been improved by the auxiliary gate located at the extremity of the weir, which allows flushing the sediments deposited in the reservoir near to the intake.

## 3. INCREASE OF SPILLWAY CAPACITY

### 3.1 GENERAL LAYOUT

The new spillway built on the left bank, instead of the existing weir, consists of three bays equipped with three 9.00 m wide, 5.91 m high radial gates. The latter are fitted with three 7.40 m wide and 2.20 m high flap gates, whose purpose is the regulation of water level and discharge of floating debris. The capacity of the spillway has been increased by lowering the sill crest by about 1.0 m and by improving hydraulic efficiency of the weir. The total spillway capacity is 915 m<sup>3</sup>/s at the maximum flood reservoir elevation (554.30 m a.s.l.), which is situated 1.10 above the normal water level. Construction of an upstream parapet on the dam crest avoids overtopping of the dam during extreme floods.

The new spillway has been built slightly downstream the existing one ("Fig.3"). In order to reduce the environmental impact, the alignment of the weir has been designed to minimise the effect on the actual structure and in particular on the chute walls. The 15.50 m long new overflow weir is slightly curved to reduce its width from 31.00 m upstream to 30.00 m downstream. The two intermediate piers are consequently varying in thickness from 2.00 m upstream to 1.65 m downstream. They are inclined upstream to facilitate the passage of floating debris. The 50 m long, 30 wide spillway chute has a 3% longitudinal slope. Excavated in sandstone, the chute is unlined with the exception of the first five meters from the downstream toe of the overflow weir.

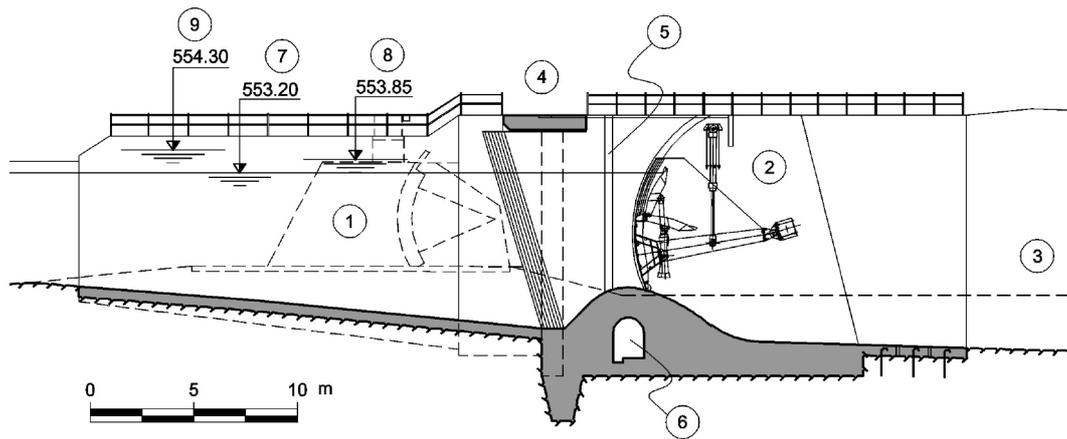


Fig. 3  
 Longitudinal section of the new spillway  
*Coupe longitudinale du nouvel évacuateur de crue*

- |                        |                                 |
|------------------------|---------------------------------|
| 1. Ancient spillway    | 1. Ancien évacuateur de crue    |
| 2. New spillway        | 2. Nouvel évacuateur de crue    |
| 3. Spillway chute      | 3. Coursier                     |
| 4. Bridge              | 4. Pont                         |
| 5. Stoplog slot        | 5. Rainure pour batardeau       |
| 6. Drainage gallery    | 6. Galerie de drainage          |
| 7. Normal water level  | 7. Niveau normal d'exploitation |
| 8. Design water level  | 8. Niveau de dimensionnement    |
| 9. Maximum water level | 9. Niveau maximal               |



Fig. 4  
 Downstream view of the new spillway of the Maigrage dam  
*Vue aval du nouvel évacuateur de crue du barrage de la Maigrage*

On the right abutment, the auxiliary spillway is equipped with the same gate as installed on the left bank spillway. The maximum discharge of the weir is 275 m<sup>3</sup>/s.

A physical model study (scale 1:50) of the Maigrauge dam and its appurtenant structures was carried out in the hydraulic laboratory of the Swiss Federal Institute of Technology Lausanne to verify the discharge capacity of the spillways and to analyse the flow conditions of the spillways and both upstream and downstream the dam in different operating conditions (MOUVET et al. 1998).

### 3.2 CIVIL WORKS

The initial construction activities of the new spillway on the left abutment included the construction of the cofferdam, which consisted of seven metal-frames driven into the sandstone supporting a waterproof sheet piling. Owing to some difficulties related to the construction of this weir, its design had to be reviewed. The frames had to be reinforced and adapted to geological conditions of the site. These problems led to some delays of the construction programme and required modifications of works procedures.

After the completion of the excavation works, the upstream cut off wall and the 1.50 m thick, 31.00 m wide and 15.50 m long apron were poured, followed by the 10.00 m high lateral walls and the two intermediate piers. For stability concerns the left wall had to be reinforced by ten 23.00 m long pre-stressed anchors executed on its top edge as well as through 50 anchor bars, which vary in length from 5.00 to 15.00 m. The three sill shaped structures were concreted between the piers in different stages in order to avoid cracking.

Due to the delay in the construction of the cofferdam, erection of the hydromechanical equipment was carried out simultaneously with the civil works, which required some coordination between different contractors.

### 3.3 HYDROMECHANICAL EQUIPMENT AND CONTROL SYSTEM

The radial gates, which equipped the new spillway are designed to close under full flow without external power supply. The gate body is composed of a 9.00 m large curved skin plate strengthened by vertical girders and by a caisson acting as a master beam. The water thrust acting on the gate leaf is transferred to the bearings by two arms, which are parallel to the piers. Hydraulic cylinders are connected to the gate arms, which have a rectangular section with variable inertia and trunnion supports are anchored in the piers and the lateral walls. The design of spillway gates and hydraulic hoists has been carried out in accordance with DIN 19704 standard.

The 7.40 m wide and 2.20 m high flap gates located on the top of the radial gates are composed by a cylinder border, stiffened and supported by a master beam in caisson. Each flap gate is operated by a hydraulic cylinder located in the centre. Flap gates are sealed along the hinged edges by a flexible flat rubber and laterally by a music note rubber. Lateral seals of the spillway gates are equipped with a heating device, which is automatically switched by a thermostat measuring air temperature.

Each gate of the spillway is equipped with a completely independent hydraulic circuit and an independent hydraulic unit equipped with two motor-pumps, a manual pump and all components for a good operation while safety devices protect the hydraulic system against eventual overpressure. The design of the hydraulic system has been carried out with a rated oil pressure of 25 MPa.

Electrical and hydraulic equipments of the spillway gates are installed in the control room built close to the weir. These gates can be operated both locally and from the main control room located in the ancient powerhouse on the right bank. The position of each gate is indicated on a control panel installed in both control rooms and controlled by a programmable logical controller (PLC). Regulation of the water level is carried out by an additional PLC installed in the main control room. The following information is collected in a central supervisor PC and transmitted to the dispatching centre of EEF:

- Set point of the reservoir level [m a.s.l.];
- Reservoir level in real time [m a.s.l.];
- Position of each radial and flap gate in [cm] and [%];
- Discharge released by each bay of the spillway [m<sup>3</sup>/s];
- Total discharged flow [m<sup>3</sup>/s];
- General alarms, and
- Different automatic monitoring measures of the dam.

Flap gates of the spillway are automatically controlled while radial gates are operated only by manually, locally or remotely from the main control room. The auxiliary gate located on the right bank is operated manually from the main control room. This gate is used for flood discharge only in exceptional situations or to replace a failing gate on the left bank.

Power equipment is supplied by the grid under 400/230 VAC and can be automatically relieved by a diesel unit in case of a grid shutdown. Control equipment is supplied by 48 VCC batteries.

### 3.4 WORK SCHEDULE AND COSTS

All civil works, hydromechanical and electrical equipment contracts were awarded in summer 2000 and construction work at the site begun in autumn 2000. The refurbishment of the Maigrage dam project was scheduled to be completed within a period of 34 months. It was divided into four main work phases: straightening of the dam and construction of the new water intake on the left abutment, including erection of the auxiliary gate, during the phases one and two, demolition of the existing spillway and construction of the new one during the third phase and finally the construction of the new parapet on the crest of the dam.

The river diversion during rehabilitation works was designed for the ten year flood of 450 m<sup>3</sup>/s. The peak discharge of the river at the site could be limited by regulation of the upstream Rossens reservoir, except from October to November when the N.O.L. is reached. During phases one and two floods were spilled downstream the dam by the existing weir located on the left bank. During the construction of the new spillway, water discharges were discharged by the auxiliary gate and over the dam crest. During the last phase the new spillway was in operation.

Difficulties experienced in constructing the new spillway led to a delay of six months compared to the project schedule. Other problems with civil works resulted in a supplementary delay of four months.

The total investment for the entire Maigrage dam rehabilitation project amounted to CHF 30 million (US\$ 25 million). Costs for the construction of the new spillway on the left abutment were CHF 9.6 million: CHF 6.8 million for civil works and CHF 2.8 million for hydromechanical equipment, including nearly CHF 0.3 million for the remote control equipment.

### REFERENCES

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- [2] MOUVET, L., HERSBERGER, D. and GOLLIARD, D. (1998) "Refurbishment of the Maigrage powerplant: contribution of scale model testing to hydraulic design". *Modelling, Testing and Monitoring for Hydro Powerplant III*, PP.365-375.

## SUMMARY

The Maigrauge gravity dam of the "Groupe e SA" was built on the Sarine river close to the town of Fribourg in Switzerland between 1870 and 1872. The dam, heightened in 1909, is the oldest concrete dam in Europe.

Although the behaviour of the 130 year old structure was satisfactory, upgrading works became necessary to adapt the dam to present safety standards. Upgrading works, which started in 2000 and were completed in 2004, included the strengthening of the dam with the installation of 52 pre-stressed anchors and the upgrading and rehabilitation of the spillways, including the installation of four radial gates with a total maximum flow capacity of 1'190 m<sup>3</sup>/s. In addition, the intake structure has been rehabilitated and the monitoring system completed.

The presentation of the main features of the Maigrauge dam, including a description of the dam layout and its operative conditions before 2000, is followed by a description of the aspects regarding safety reassessment and various solutions aimed to improve the dam's safety. The paper focuses on its hydraulic safety. Further, it illustrates upgrading works and in particular the design and the construction of the new spillway located on the left bank.

## RÉSUMÉ

Le barrage poids de la Maigrauge, propriété des "Groupe e SA", a été construit entre les années 1870 et 1872 sur la Sarine à proximité de la ville de Fribourg, en Suisse. Le barrage, surélevé en 1909, est le plus vieux barrage en béton d'Europe.

Bien que le comportement du barrage pendant une période de quelque 130 années ait été entièrement satisfaisant, des travaux de réhabilitation se sont avérés nécessaires pour adapter l'ouvrage aux directives de sécurité actuelles. Ces travaux, débutés en 2000 et achevés en 2004, ont inclus le confortement du barrage par le biais de 52 tirants précontraints, l'accroissement de capacité et l'assainissement des évacuateurs de crue, y compris l'installation de 4 nouvelles vannes segment avec une capacité totale de 1'190 m<sup>3</sup>/s. Les ouvrages de dérivation ont été également assainis et le dispositif de surveillance du barrage mis à jour et complété.

La présente contribution débute par la description de l'aménagement de la Maigrauge et de ses conditions d'exploitation avant l'année 2000, et poursuit par la présentation des différents aspects afférents à la sécurité du barrage et des solutions mises en œuvre pour atteindre les objectifs de sécurité fixés. L'article se concentre essentiellement sur la sécurité en cas de crue et sur l'illustration des travaux de réalisation du nouvel évacuateur de crue situé en rive gauche.