9TH ICOLD EUROPEAN CLUB SYMPOSIUM

SHARING EXPERIENCE FOR SAFE AND SUSTAINABLE WATER STORAGE

MIGNANO DAM REHABILITATION

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Background

Mignano dam on Arda river (river Po valley, Italy) is a large gravity mass concrete dam built in 1926-1933, 341 m long and 55 m high, with a total volume of 230.000 m^3(Figure 1). The dam is subjected from several years to water level restrictions until the finish of some rehabilitation works (now completed) finalized to reach the complete dam efficiency, safety and the maximum utilization of the reservoir (14 Mm^3) by the Concessionaire, "*Consorzio di Bonifica di Piacenza*", mainly for agricultural use (irrigation of the Arda valley) and also for drinking-water use.

Some cases of damage experienced on spillways chute and stilling basins (e.g.: Malpaso, Tarbela and Karnafuli dams), operating under flood conditions, showed that conventional design methods had been correctly applied but they were not sufficient to avoid damages in the linings.

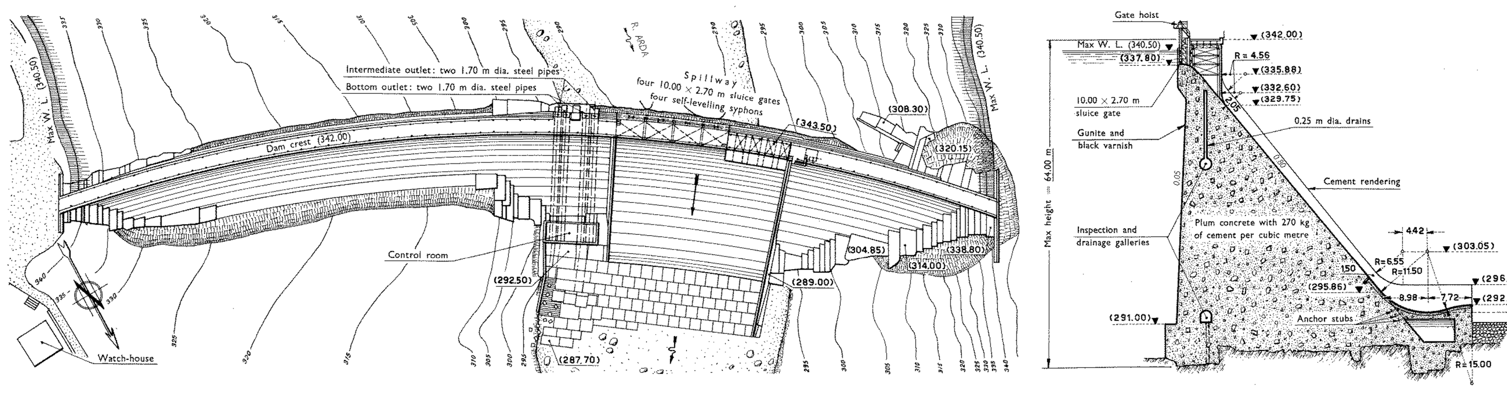


Figure 1: plan view and main cross section of Mignano dam until 1997

Goals

Mignano dam rehabilitation required:

- an exhaustive hydrological study to define the design discharge (800 m^3/s, T=1000 years) for the overfall spillway extension and new stilling basin;
- physical modeling (1:40 geometric scale, according to Froude similarity) to check the hydraulic behavior of the designed structures.

Physical modeling was focused on stilling basin concrete slabs stability design criteria, measuring directly forces and pressures (using force and pressure transducers) acting on the slabs at the bottom of the stilling basin in the hydraulic jump region. Tests were performed for 24 hours duration, corresponding to a prototype flood duration of about 6 days to evaluate the temporal evolution of the highest uplift forces acting on the lining. The experimental results allowed to define a design criteria of the equivalent thickness that should be assigned to the concrete slabs to assure the stability of the lining in the stilling basin.

Figure 2: dam downstream view after spillway lengthening

Hydrological analysis

At the dam site, the river catchment extension is 87.20 km^2, length of the riverbed 14 km, average altitude 748 meters a.s.l., and maximum elevation is Menegosa mount (1355 m a.s.l.).

The evaluation of the peak flow discharge for different values of return period was performed using the statistical distributions of literature: Gumbel (EV1), Maione-Gumbel (M.G.), Generalized Extreme Value (G.E.V.), and also the regionalization model adopted by the *River Po Basin Authority* (Figure 3).

Models' calibration was performed using the time series of annual maximum peak flood discharge recorded from 1931 to 1997 (64 years of observations). The results (Table I), and in particular those relating to T=1000 years, show that the values obtained are significantly different from each other: vary from a minimum of 456 m^3/s (Gumbel) to a maximum of 803 m^3/s (*River Po Basin Authority* regionalization model).

The *Italian government surveillance on dams*, heard the *National Hydrographic Office*, decided to adopt the value of **800 m^3/s** as a suitable and conservative value of peak flow discharge to be taken in the design of the new stilling basin and in lengthening of the spillway.

Table I: estimated peak flood discharges for different return periods

T (years)	Gumbel (m^3/s)	G.E.V. (m^3/s)	M.G. (m^3/s)	R.PoB.A. (m^3/s)	Average (m^3/s)
100	325	365	382	672	436
200	365	446	421	708	485
500	417	576	471	754	555
1000	456	695	507	803	615

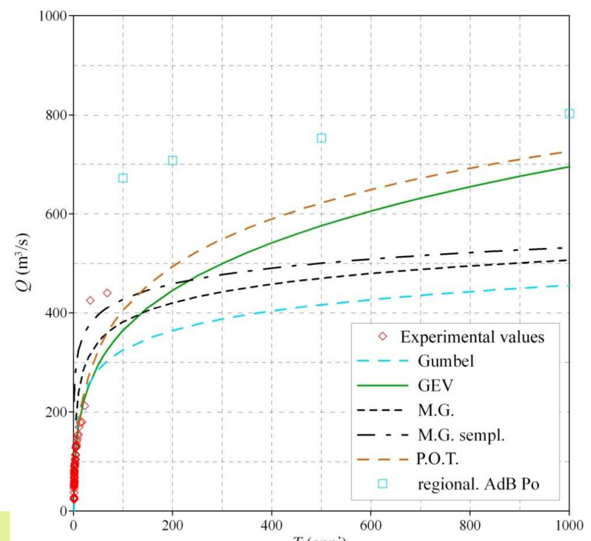


Figure 3: probability distributions and observed values

Main works description

- <u>Lengthening of the existing spillway</u>, from 6 sills to 8 sills, through two new sills in the left (net length of 21.0 m, design head equal to 1.7 m, Figure 2), shaped according to Creager profile;
- <u>New bridge spans above new spillway sills n. 7 and n. 8</u>;
- <u>New stilling basin at the toe of the extended chute spillway</u>, in reinforced concrete, 80 m wide, 45 m long (Figure 4 and Figure 5), bottom elevation at 290.00 m a.s.l.; at the downstream end a weir 50 m long, crest elevation=293.95 m a.s.l. controls the hydraulic jump. Sides of the stilling basin are delimited by two walls in reinforced concrete which ensure the control of the maximum water height (8 m above the bottom) with a free height of 2 m. The bottom lining of the stilling basins is provided with **reinforced concrete slabs of dimensions 4×8 m, with largest dimension parallel to the river bed direction, and an increasing thickness from 1.05 m (downstream) to 2.90 m (upstream)**. The design, verified on physical model, was made to withstand the dynamic actions resulting from pressure pulsations which are generated by the hydraulic jump, characterized by peak values which may even reach the order of magnitude of the kinetic height referred to the supercritical incident flow. Slabs' stability is ensured simply "*by weight*" varying their thickness "*in order to ensure a proper safety factor*" (always >10%).

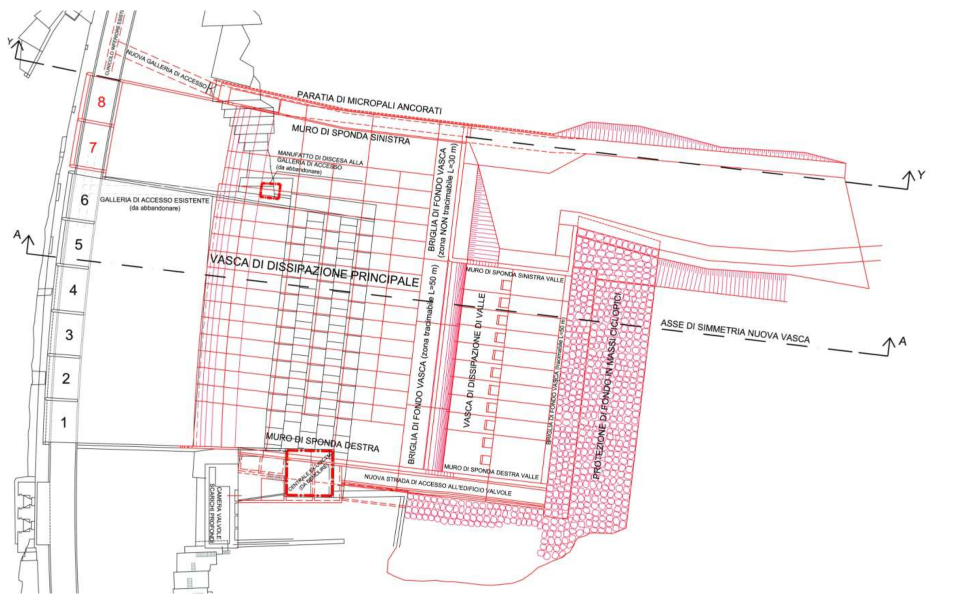


Figure 4: middle part of the dam plan view (red color: projected works)

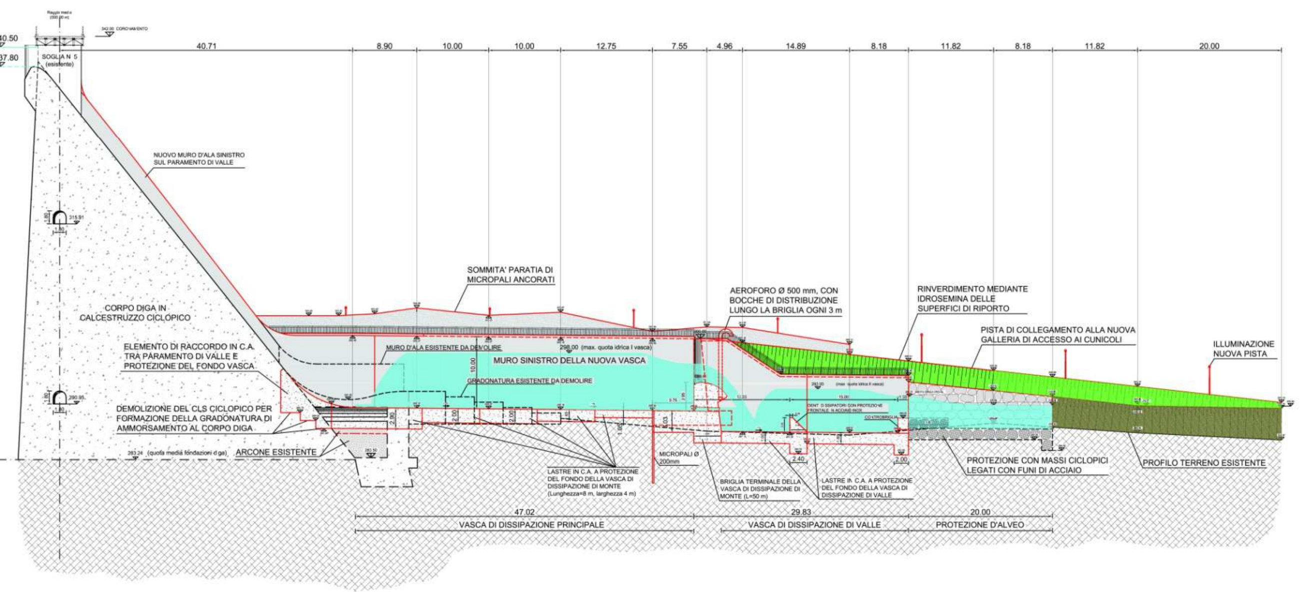


Figure 5: longitudinal section A-A along the center-line of the new stilling basin (red color: projected works)

Figure 6: experimental setup

Physical model tests and experimental details

An investigation on the stilling basin slab stability was performed in 2002 at *University of Trieste*, *Civil Engineering Department*, by Prof. Elpidio Caroni and Prof. Virgilio Fiorotto, modeling the dam in a 1:40 geometric scale, according to the Froude similarity, in order to **measure forces and pressures acting on the slabs at the bottom in the hydraulic jump region** (Figure 6).

An <u>aluminium frame 1000 mm long, 500 mm wide and 25 mm thick</u> with a central rectangular hollow, 10 mm deep, was inserted in the stilling basin bottom. Inside the hollow, a movable aluminium slab (100x200 mm), 8 mm thick, was cast with the upper face at the same level of the stilling basin flume (Figure 7).

Each <u>force transducer</u> was placed in a rigid waterproof perspex box, with 10 mm thickness walls, fixed to the aluminum frame. Force transducers (TS100 of AEP Transducers) with a sensitivity less than 0.1 N, and a response time lower than the microscale time of the pulsating forces were used.

Five <u>pressure taps</u> were inserted on the basin bottom, aligned with the center of each slab at a different distance from the spillway base; the pressure taps have a diameter of 2 mm and were connected to the transducers by a rigid tube of 4 mm internal diameter. Pressure transducers of type Foxboro FPT adjusted in the range 0-70 kPa where adopted: they have a response time (10-90%) of 1 ms that is lower than the microscale time of the pulsating pressure.

During tests <u>data were achieved at a 150 Hz frequency rate, according to the Nyquist criterion</u>, for a 24 hours duration, corresponding to a prototype flood duration of about 6 days (Figure 8).

As related to the slab design criteria, the <u>maximum pressure and force fluctuations are of interest</u> (Figure 9).

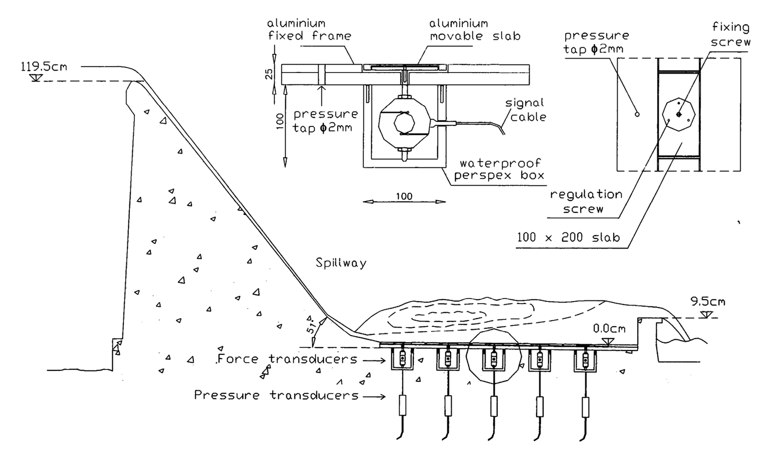


Figure 7: experimental setup for measuring uplift forces

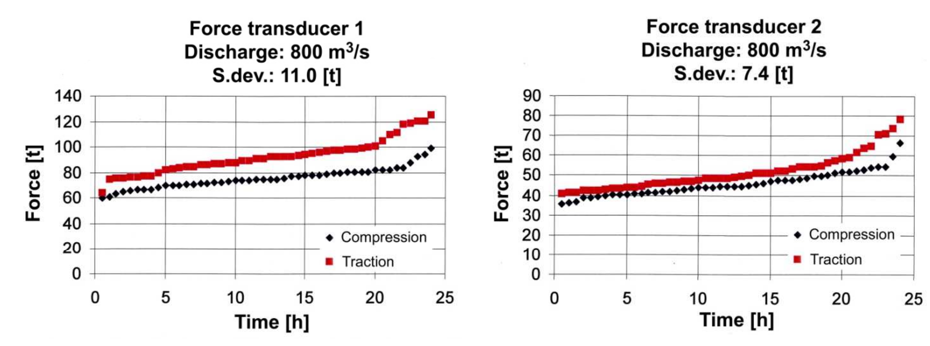
Figure 8: stilling basins operating with the design discharge (Q=800 m^3/s)

Design criteria

The experimental results allow to **define the <u>equivalent thickness</u> to be assigned to the slabs assuring the stability of the lining in the spillway stilling basin** (Table II). Referring to the design discharge of 800 m^3/s the minimum fluctuating pressure in the prototype is lower than the water vapor pressure, so that cavitation effects are not taken in account. In these cases, the equivalent thickness *s* can be directly computed using the following equation: $s = F'_{max}/(\gamma_c-\gamma)l_x l_y$, where γ_c and γ are the specific weight of concrete and water, respectively, l_x and l_y slab dimensions, and F'_{max} represents the maximum uplift force measured in the model. The safety coefficient here employed is always greater than 10%.

Table I: max measured forces and thickness to be assigned to the slabs for the design discharge

	Slab n.	Max. force (t)	Min. thickness (m)	Design thickness (m)
Upstream	1	125.0	2.60	2.90
	2	78.7	1.70	2.90
	3	83.8	1.80	2.00
	4	70.3	1.50	1.65
Downstream	5	32.0	0.70	1.05



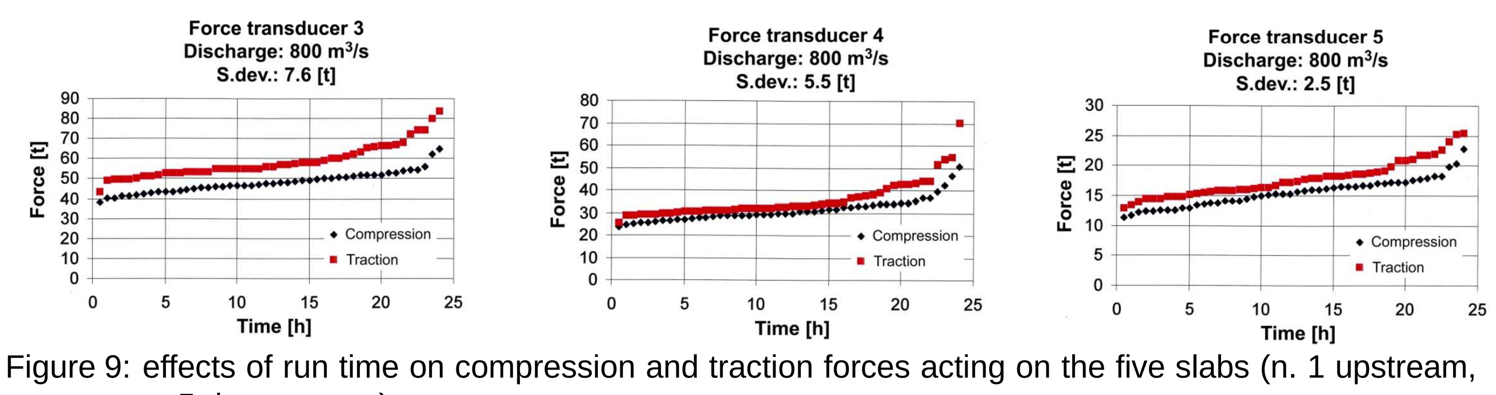


Figure 9: effects of run time on compression and traction forces acting on the five slabs (n. 1 upstream, n. 5 downstream)

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