Hydraulic and operational safety evaluation of some existing Portuguese large dams

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SYNOPSIS. The Portuguese Regulations for Safety of Dams came into force in 1990, after being published as a Decree-law. Since then some rules and guidelines concerning the different stages of the life of dams have also been published, to complete and to help the application of the law.

Following the occurrence of problems during flood events in 1995-96, with the overtopping of a few small dams, and with incidents at some large dams, that could be controlled but, nonetheless, were of great concern, the Portuguese authorities decided to launch a specific program for the safety reassessment of the existing large dams in the country.

For that purpose 11 calls for tenders were made for the study of 38 large dams, concerning all aspects of structural, hydraulic and operational safety, and also including studies of the downstream valleys for dam failure scenarios.

The safety studies were based on all the hydrological data available today, on the original projects and other elements related to dam features, on behaviour records and on site inspections. Some relevant conclusions were reached in these studies. It was also shown that in some cases compliance with current safety regulations had not been met.

The results from the evaluations carried on the hydraulic and operational safety and the actions proposed to lower the risk are presented, where cases of significant hazard at the downstream valley or risk to the structure of the dam are considered to exist. Measures that are currently being undertaken , or will be pursued in near future, are also discussed.

Long-term benefits and performance of dams. Thomas Telford, London, 2004

LONG-TERM BENEFITS AND PERFORMANCE OF DAMS

INTRODUCTION

Although dams have an important role in the development of communities they also imply risks, however small, for people and for economical and social activities in the downstream valley that could be affected by the failure of the dam.

The existence of these risks was highlighted in Portugal by the occurrence of problems during flood events in 1995-96, with the overtopping of a few small dams, and with incidents at some large dams, that could be controlled but, nonetheless, were of great concern.

An evaluation of the safety conditions of Portuguese dams is necessary to prevent major accidents due to dam failures or, at least, to mitigate their consequences.

For that matter, due to the lack of human resources within the public administration, a decision for preparing tenders for specialized outsourcing was taken by the Institute of Water (INAG), in 1999. INAG is the Portuguese Authority in dam safety, and has the technical support of National Laboratory of Civil Engineering (LNEC), as defined by dam safety regulations. A total of 11 tenders, concerning 38 large dams, were launched.

As this first group of dam safety studies is concluded, very soon another group of dams will be included in new call for tenders. This plan will continue until all dams of significant or high risk are studied.

PURPOSE OF UNDERTAKEN STUDIES

The major purpose of these studies is to get an accurate revue of the safety conditions of the Portuguese dams regarding the regulation for safety of dams, and to identify the remedial measures that have to be implemented by the owners to improve safety to the new standards.

These studies should include an assessment of the structural and hydraulic-operational safety, a global risk index computation, a possible change of the rules of exploitation of the reservoir, the mapping of the downstream areas affected in case of dam failure, the assessment of downstream risks and the proposal of an alert and warning system.

Also they should propose some immediate measures to be taken to solve simple problems. Major deficiencies or corrective works, including civil works, electric and mechanic equipments, observation systems and alert and warning systems, are identified in the studies but need further analysis and design from the dam owners, to be approved and implemented.

CHOICE OF THE DAMS

The 38 dams that made part of this first group of tenders were chosen after an assessment that included preliminary field inspections. All of these dams had been designed before the new regulations were mandatory, all of them showed several deteriorations and it also was established that for the great majority the associated potential risk was either significant or high.

This group of dams comprised most of the oldest large dams built in the country for irrigation, and also a representative group of more recent dams with that same purpose.

The majority of these dams had shown during the preliminary inspection that there was no observation plan and that no inspections took place regularly, so that the observation activities were very deficient.

Also some of them showed what appeared to be signs of structural problems that needed to be studied to determine and implement the corrective measures.

In some cases the outlet works didn't work and the dams showed lack of maintenance of the equipments and of the structure itself.

The personnel responsible for the exploitation of the dams in some cases had no specific preparation and didn't fully understand how to correctly operate gates and valves.

The chosen dams are mainly situated in the interior northern part of country and in the southern part near the coastline, as can be seen in Figure 1, and their characteristics can be seen in Table 1.

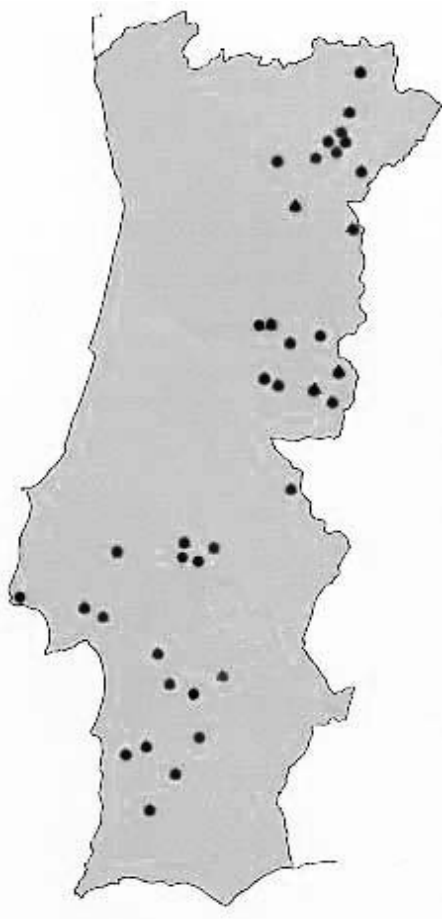

Figure 1. Location of the dams

Table 1: List of studied dams

Dam	End of construction	Age (years)	Type	Use	Height (m)	Reservoir (hm^3)
Alfândega da Fé	1970	33	TE	SI	25	1.60
Alijó	1991	12	TE	S	40	1.74
Alvito	1977	26	TE	SI	49	132.50
Apartadura	1993	10	ER	SI	46	7.50
Azibo	1982	21	TE	SI	56	54.50
Burga	1978	25	TE	I	35	1.80
Camba	1993	10	TE	SI	35	1.10
Campilhas	1954	49	TE	SI	35	21.70
Capinha	1981	22	TE	S	18	0.52
Carviçais	1984	19	TE	S	20	1.20
Cova do Viriato	1982	21	PG	S	24	1.50
Covão do Ferro	1956	47	PG	H	32.5	0.87
Fonte Serne	1977	26	TE	I	18	5.20
Furadouro	1959	44	PG+TE	I	17	0.40
Gameiro	1960	43	PG+TE	IH	20	1.30
Gostei	1993	10	TE	I	35	1.40
Idanha	1949	54	PG	IH	54	77.80
Magos	1938	65	TE	I	17	3.00
Maranhão	1957	46	TE	IH	55	205.00
Marateca	1991	12	TE	SI	23.8	37.20
Meimoa	1985	18	TE	SI	56	40.90
Montargil	1958	45	TE	IH	48	164.00
Monte da Rocha	1972	31	TE	SI	55	104.50
Odivelas	1972	31	MV+TE	I	55	96.00
Pego do Altar	1949	54	ER	IH	63	94.00
Peneireiro	1973	30	TE	S	15	0.80
Penha Garcia	1979	24	PG	SI	25	1.10
Pisco	1968	35	TE	S	24.5	1.40
Ranhados	1986	17	PG	S	41	2.60
Rio da Mula	1969	34	PG+TE	S	17	0.34
Roxo	1967	36	CB+TE	SI	49	96.30
S M Aguiar	1981	22	TE	SI	20	5.40
Salgueiro	1975	28	TE	I	25	1.80
Santa Clara	1968	35	TE	ISH	86	485.00
Toulica	1979	24	TE	IS	16	2.00
Vale das Bicas	1939	64	TE	I	12	2.00
Vale do Gaio	1949	54	TE/ER	IH	51	63.00
Venda Velha	1957	46	TE	I	14	4.64

RESULTS

In Portugal nowadays around 180 large dams according to the ICOLD definition exist, mostly for hydropower and irrigation purposes, many of them more than 30 years old. In the 40's and 50's those that were built for irrigation and water supply were directly promoted by the State, through a specific department that gained a large experience in dam design and construction. More recently, however, we have seen an increasing number of dams constructed as a result of private investment or various public departments and local authorities with a less developed history of dam operation and construction. On the other hand, the operation of irrigation and supply dams has been judged inadequate, with a lack of adequate technical and financial resources identified. As a result a significant number of problems have led to specific direct interventions by dam safety public authorities.

Some cases where safety did not comply with safety regulations

The assessment of the compliance of the hydrologic, hydraulic and operational safety of dam in Portugal has to be made for the return periods imposed by the existing regulations. Those return periods can be seen in Table 2, where it can be seen that "potential risk" has a vital role in defining which one to adopt.

Table 2: Return periods imposed by the RSB

Dam		Potential risk	
Concrete	Embankment	High	Significant
$h \geq 100$	$H \geq 50$	10,000 to 5,000	5,000 to 1,000
$50 \leq h < 100$	$15 \leq h < 50$	5,000 to 1,000	1,000
$15 \leq h < 50$	$h < 15$	1,000	1,000
$h < 15$	-	1,000	500

The potential risk is defined in Portuguese regulations as a measure of the consequences of an accident, not withstanding the probability of its occurrence, and can be sorted by the following levels, according to the loss of human lives and economic damages:

- low, when no lives are in threat and there are few economic damages
- significant, when some human lives can be lost and the economic losses are of some importance
- high, when an important number of lives can be lost an the economic losses can be high

Therefore, to determine which return period to apply to the design flood of spillways one must do the study of the areas affected by the wave resulting of the failure of the dam and determine the number of human lives that

could be considered at risk and of the economic losses and infrastructures affected.

In these 38 cases only 2 of them are considered of low potential risk, 7 of significant risk and the rest are considered of high risk. In some cases the results of the studies includes an estimate of the number of lives that could be in danger, the number of homes and a list of other infrastructures that could be affected by the flood wave, such as schools, public services and civil protection structures, roads, railways, bridges and others.

Table 3: Potential risk of the dams

Dam	Scenario	Estimation			Potential risk		
		no. lives	no. homes	Infrastr-uctures	low	signif-icant	high
Alfândega da Fé	overtopping		3	Yes		x	
Alijó	piping	57	22	Yes			x
Azibo	piping	518	192	Yes			x
Burga	overtopping		78	Yes			x
Camba	piping	29	11	Yes			x
Cova do Viriato	sudden breach	175		Yes			x
Covão do Ferro	sudden breach	378	140	Yes			x
Fonte Serne	piping			Yes		x	
Furadouro	sudden breach			Yes	x		
Gameiro	sudden breach			Yes	x		
Gostei	piping	322	119	Yes			x
Maranhão	overtopping			Yes			x
Marateca	piping	216	80	Yes			x
Meimoa	overtopping	1566	580	Yes			x
Peneireiro	overtopping		87	Yes			x
Penha Garcia	sudden breach			Yes			x
Pisco	overtopping			Yes		x	
Ranhados	sudden breach	57	21	Yes			x
Salgueiro	overtopping		58	Yes			x
Toulica	piping	4		Yes		x	
Vale das Bicas	piping	35	13	Yes			x
Vale do Gaio	overtopping			Yes			x
Venda Velha	piping	105	39	Yes			x

Comparing the return periods in Table 4 we can see that generally those determined in the hydrological studies made are greater than the ones adopted in the original studies. The consequence is that the peak flows that result of hydrological studies should be greater than the original ones. But analysing Table 4 we can see that in some cases the peak inflows are lower

and in a considerable number of them the peak inflows are almost unchanged. It was seen that it had mainly to do with the new amount of data available today, the new methodologies that are currently used, considered more accurate, and in some cases with mistakes in the original studies that now have been detected and corrected.

In some cases, however, like in Fonte Serne, Magos, Meimoa and Vale do Gaio dams, the peak inflows were over 100% higher.

Table 4: Results of the hydrological studies

Dam	Catchment area (km^2)	Return period		Peak inflow (m^3/s)		Volume (hm^3)	
		initial	new	initial	new	initial	new
Alvito	212,00	100	1000	1300	598		
Capinha	6,30	1000	5000	32.5		0.334	
Cova do Viriato	2,30	100	1000	34	43	0.106	0.299
Fonte Serne	32,00	500	1000	55	125		
Furadouro	3374,00	500	1000	2300	2415		248.0
Gameiro	3255,00	500	1000	2800	2390		240.0
Idanha	362,00		5000	700	1168	43.20	48.40
Magos	105,00		1000	110	279		11.50
Meimoa	61,00	1000	5000	228	505	4.840	14.00
Montargil	1182,00	500	5000	1200	1764	80.00	197.0
Pisco	13,95	?	1000	100.6	105.9	0.362	0.666
Rio da Mula	3,00		1000	22	35	0.060	0.194
Roxo	350,00	1000	1000	740	1232	18.30	35.00
S M Aguiar	128,60		1000		218.6		7.700
Santa Clara	520,00	1000	5000	2000	2482	65.00	100.0
Toulica	26,00	100	1000	80	100	0.614	2.395
Vale do Gaio	509,00		5000	750	1762		
Venda Velha	174,00	100	1000	300	327		18.63

In some other cases the peak inflows remained almost unchanged presenting only variations of about 10%. This happened in 11 dams for which either the design was recent or the studies then showed the cautiousness of the designer.

Looking at the performance of the dams we can see that 30 % of the spillways do not present a discharge evacuation capacity that complies to the new regulation. In these cases construction of a new spillway or modifications of the existing spillway or dam operational constraints are required for re-establishing compliance with current statutory constraints and guidelines.

Toulica dam, for instance, is overtopped in all the studied scenarios, even for 100 years return period flood with 3tc, where tc is the time of concentration of the dam drainage basin. This fact led to a restriction being imposed on the level of the reservoir 2 meters below NPL so it can deal with a 100 year flood with 1tc.

But there are several other cases of insufficient spillway capacity. Montargil, Fonte Serne, Cova do Viriato, Roxo, Meimoa, Magos, Rio da Mula, SM Aguiar, Vale do Gaio, Venda Velha and Pisco dams showed this problem, although the magnitude of it varies significantly.

Table 5: Performance of the spillways

Dam	Spillway type	Gates (y/n)	Spillway capacity (m^3/s)		Discharge evaluation (y/n)	
			Initial	Revised	Satisf-actory	Over-topped
Camba	Surface	no	40	39	yes	no
Carviçais	Surface	no	45	17	yes	no
Cova do Viriato	Surface	no	3.8	18	yes	no
Covão do Ferro	Surface	no	7	20	yes	no
Fonte Serne	Surface	no	36	68	no	no
Magos	Surface	yes	110	195	no	no
Maranhão	Shaft	yes	1600	1987	yes	no
Marateca	Surface	yes	60	77	yes	no
Meimoa	Surface	yes	124	240.5	no	no
Montargil	Shaft	yes	765	1022	no	no
Pisco	Surface	no	43	77.5	no	no
Ranhados	Surface	no	215	140	yes	no
Rio da Mula	Surface	no	7.8	26	no	no
Roxo	Surface	no	64	161	no	no
S M Aguiar	Surface	no	155	200	no	no
Salgueiro	Surface	no	29	20	yes	no
Santa Clara	M glory	no	208	213	no	no
Toulica	Surface	no	17.6		no	yes
Vale das Bicas	Surface	no		107.9	yes	no
Vale do Gaio	Shaft	yes	1000	1200	no	no
Venda Velha	Surface	no	140	236	no	no

In some cases like the Marateca dam and Camba dam the spillways expected performance is near acceptable, with the anticipation of some damages for the revised design floods but without any kind of danger to the structure of the dam.

Results from the evaluation undertaken on hydraulic and operational safety of dams

One of the main conclusions of these studies relates to some features that the actual law imposes on hydraulic and operational safety, namely the need for the gates to be operated locally and from a distance, and to have two different energy sources available, besides being manoeuvred also manually.

Those requirements apply also to bottom outlets, which are sometimes too demanding and make it very difficult for existing dams to comply.

The legislation imposes the need for operational manuals at each dam, which should namely include guides for the reservoir exploitation, as well as rules related to all the equipment operation and the necessary measures for maintenance and conservation. The manuals were found to be lacking on the studied dams. In these studies this lack of information was highlighted, procedures were drafted and proposed for implementation as soon as possible.

The operational procedures are of great importance to dam safety because the operation personnel in most of the studied dams revealed lack of understanding of the equipment installed and of the right procedures to operate them, in response to reservoir conditions. This is more dangerous in cases where spillway gates exist, because it can endanger the dam itself.

The bottom outlets in some cases like Penha Garcia, Cova do Viriato and Pisco dams were out of order and so, in case of an emergency, it would be impossible to lower the reservoir. In other cases like Venda Velha, Vale das Bicas, Toulica or Magos dams the bottom oulets were operating poorly but allowing some kind of control of the reservoir.

The amount of financial resources needed in some cases makes it difficult for owners to comply with the legislation.

Actions proposed to lower the risk

As indicated by the studies, measures to lower the risk in some dams led to restrictions imposed on the operation of the reservoirs such as lowering normal storage levels, and alternative design of solutions for spillways and other elements.

This was the case of Meimoa, Fonte Serne, SM Aguiar and Toulica dams, where reservoir levels were conditioned to prevent damages. Those levels were determined in each case after discharge evaluations were made for the chosen design floods and the consequences were assessed.

In other cases, when there were serious problems of reliability and performance of the spillways, it was decided that it was necessary to improve their discharge capacity by modifying the existing one or by designing an auxiliary spillway. This was the case of Capinha, Montargil and Roxo dams.

Some cases of rehabilitations underway

Due to heavy rainfall in December 2000 the spillway of Pisco dam suffered huge damages that threatened the dam itself and motivated emergency intervention. After some remedial work was performed in the spillway, so as to make it endure a small flood, a designed for a new spillway and bottom outlet was made by the consultants involved in the safety studies. Afterwards works were awarded to a contractor and construction now is completed.
Fig. 2 depicts an intermediate phase of the works, with the new spillway completed alongside the old one. Afterwards, a new intake tower and intake and bottom discharge tunnel were constructed at the old spillway section, and the earth fill was remade.

Figure 2. New spillway of the Pisco dam alongside the old one.

Cova do Viriato dam is being subjected to several interventions destined to install a new bottom outlet and a new stilling basin, due to accommodate the increased spillway discharge capacity, and to benefit the water intakes and other supply equipments. Also the gates and valves will be operated locally

and from a distance, and they will have two different energy sources for operation, besides manual operation.

Due to the insufficient spillway capacity of Fonte Serne dam a new spillway design for the studied flood was prepared. It will be implemented as soon the owner can call a tender.

Other designs were made to improve safety conditions in hydraulic structures or equipments that will be implemented by the owners as soon as resources are available for that purpose.

Measures initiated and to be continued in the near future

The immediate actions necessary to increase safety resulting from these studies are recommended for implementation as soon as possible to prevent, accidents and avoid endangering lives.

Once the studies have been completed, meetings will take place with owners to discuss all the new available information and to decide on measures to be undertaken.

Most of the concerned owners for the studied dams are irrigation associations, which have some difficulty in obtaining funds to perform necessary interventions, because the amount of money needed to fully and immediately comply with regulations is beyond their current available resource. For this reason interventions have to be sorted in order of risk and programmed in a structured manner.

CONCLUSIONS

The results of the safety studies made for this first group of dams showed that, in spite of the amount of work that needs to be done so that the dams comply with existing safety regulations, the global picture is nonetheless of moderate concern. It is however essential that corrective measures in some structures and hydraulic equipments are undertaken.

It is necessary that dam owners comply with their legal responsibilities, being the Authority's role to guarantee that they do it. For dam owners, and Engineers who are responsible for supervising dam operation and safety, it is fundamental to acquire the knowledge of the problems and implications related to their dams. They require to have the resources in place to implement safety and operation procedures to ensure that the necessary interventions and tasks can be carried out in a phased approach.

To protect lives and to prevent economic losses in the valleys downstream it is also necessary to develop and implement Emergency Plans. These plans

are divided, in Portuguese regulations, into the "Internal Emergency Plans", that concern the dams operation and the downstream nearby areas, where the owners may be responsible for the first actions and warnings, and the "External Emergency Plans", directed by the Civil Protection Departments.

New studies will be launched, aiming at improving the Portuguese large dams' safety, especially for those private and public owned dams in which owners don't have the demanded expertise.

To implement studies recommendations, an increase both in the Authority's organization and in dam owners' safety efforts will be needed. This will also imply an increase in new investments by all entities involved.

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