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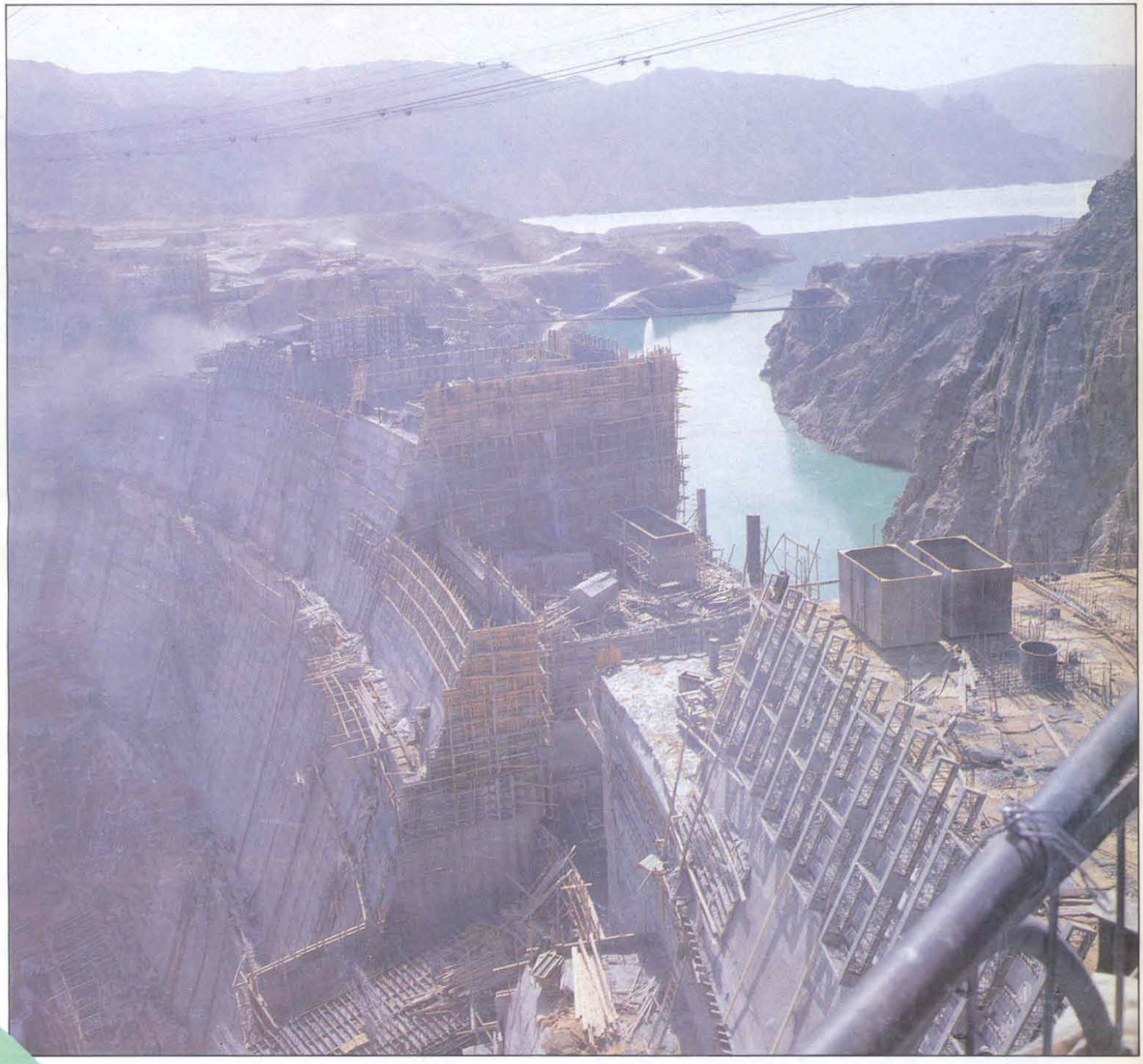

SPECIAL ISSUE

A monitoring programme for embankment dams
Hydro developments in China
Roman dams in Portugal

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Roman dams in southern Portugal

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The results of the inventory and characterization of the Roman dams in southern Portugal are briefly presented. This study was based on bibliographical analysis inquiries, information provided by archaeologists and field surveys. Eight unknown Roman dams and ten others already mentioned in publications were recognized. A typological classification is presented here.

Roman engineers were the first major dam builders in the Mediterranean area and in the Middle East, not only for water supply but also for irrigation and other purposes such as ore treatment and hydropower.

In Spain the three largest known Roman dams (Proserpina, Cornalbo and Alcantarilla, the first two still in operation), and a large number of smaller ones, are concentrated in the drainage basins of the rivers Guadiana (Merida nucleus), Tagus (Toledo nucleus) and Ebro[1].

The presence of Roman dams in southern Portugal would be expected, although no systematic research has been carried out. The only inventory on Portugal was a list drawn up by V. S. Mantas[1]. This list refers to the location of several Roman dams and has a bibliography. The information given by the bibliographical references is usually scarce and, in many cases, it is limited to the simple mention of the dams, without any indication of their precise location.

Results of the inventory

The present inventory of Roman dams south of the Tagus river began with an analysis of the available published information and enquiries to local authorities and associations. Information was also obtained from the IPPC (Instituto Português do Património Cultural — Portuguese Institute of the National Heritage), as well as from a large number of archaeologists and through contact with local people.

The inventory and characterization of the Roman dams south of the Tagus is summarized in Fig. 1; eight Roman dams unknown until now have been indentified. The Roman dams south of the Tagus were intended mainly for water supply, irrigation or both.

The drainage basins of the dams are in regions of annual average precipitation less than 800 mm and in almost two thirds of cases, less than 600 mm (Fig. 1).

The water courses have an extremely irregular regime, being dry for most of the year. The run-off water could only be used if it was stored in reservoirs. Difficulties in managing floods would have also led to the construction of dams in river sections where drainage basins were small. Table I shows the distribution of dams according to the area of the drainage basin, A(km²):

Table I — Drainage basin areas vs number of dams

$A \leq 1$ = 7 dams	$3 < A \leq 10$ = 2 dams
$1 < A \leq 3$ = 7 dams	$10 < A \leq 40$ = 2 dams

Dams 19 and 20 (Table II), Represa (Gavião) and Monte Novo (Évora), have not been included in this list because their Roman origin is unconfirmed[2]. Many of the inventoried dams were associated with villas. The way of life in the villas was deeply influenced by Rome; they generally had baths which, in the region under consideration, were frequently supplied by the associated reservoirs.

Many of the Roman dams in Portugal are small in height (Table II). The number of dams varies according to the maximum height (H), (visible height or probable height in case of partial destruction, in m) in the following way:

Table III — Height vs number of dams

$H \leq 2$	8 dams
$2 < H \leq 4$	7 dams
$4 < H \leq 5.2$	3 dams

As before, dams of unconfirmed Roman origin have not been included.

Table IV — Type of construction

Description	No. of dams
Wall with a rectangular section	7 dams
Wall with a rectangular section and downstream buttresses	8 dams
Wall with a downstream earthfill	1 dam
Double wall with an intermediate earthfill and buttresses	1 dam
Earthfill (maximum height of 0.8 m)	1 dam
Rectilinear plan	13 dams
Poligonal plan	2 dams
Curvilinear plan	3 dams

Of the 18 dams 15 are of the usual Roman type consisting of a wall made of a nucleus of *opus caementicium* (rockfill) or *opus incertum* (earthfill), externally lined with blocks, with or

(Continued on page 40)

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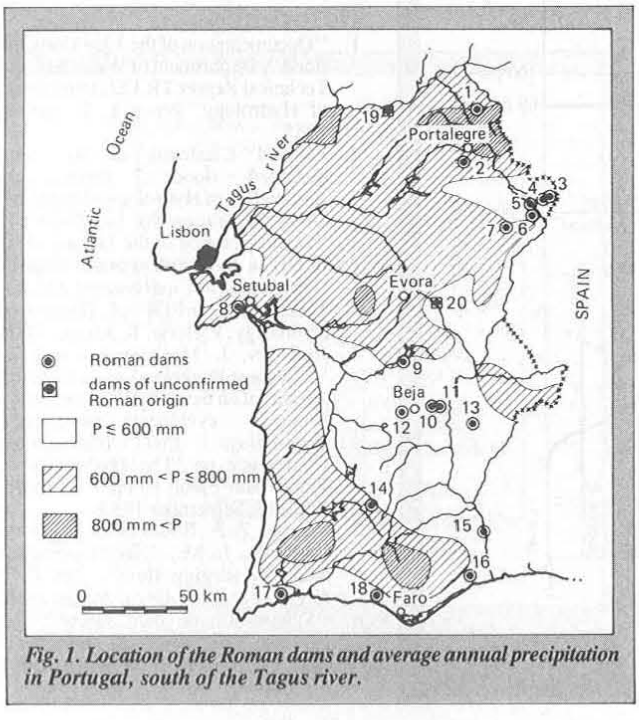

Fig. 1. Location of the Roman dams and average annual precipitation in Portugal, south of the Tagus river.

Table II — Roman dams south of the Tagus river

	Designation	Typology (structure/plan)	Dimensions (m)	Drainage basin area	Nearest known Roman site	Probable purpose	Bibliography
1	Tapada Grande (Castelo de Vide)	WE/R	H=1.6 L=76 Th=0.6 Earthfill Th (top)=0.6 Th (base)=12.6	0.3	Press device about 60 m away. Villa about 1300 m away	Irrigation	Rodrigues; 1975
2	Almarjão (Crato)	WR/R	H=5.2 L=55 Th=2.2	5	130 m	Water supply and irrigation	Saa; 1959
3	Muro (Campo Maior)	WB/P	H=4.6 L=174 Th=4.2 Buttresses: Th=1.5 Spac=3.5	1.7	380 m (possible connection with a villa 2700 m away)	Water supply and irrigation	Quintela et al; 1985
4	Olivã (Campo Maior)	WB/R	H=3 L=45 Th=0.8 Buttresses: Th=1 Spac=3	1.1	1100 m	Irrigation	Quintela et al; 1985
5	Mourinha (Campo Maior)	WR/R	H=1 L=100 Th=0.4	0.04	380 m	Irrigation	Quintela et al; 1985
6	Moralves (Elvas)	WR/R	H=3.2 L=161 Th=1.1	6.6	1500 m	Irrigation	Quintela et al; 1985
7	Carrão (Elvas)	WR/R	H=1.7 L=117 Th=1 Buttress (1): Th=1.2	1.3	140 m	Water supply and irrigation	Quintela et al; 1985
8	Comenda (Setúbal)	WB/R	H=3.7 L=13 Th=1 Buttress (1)	2.6	1000 m	Water supply and irrigation	Costa; 1905
9	Nossa Senhora da Represa (Cuba)	WB/C	H=1.8 L=81 Th=1.6 Buttresses: Th=1.3 Spac=8	2.5	620 m	Irrigation	Viana; 1947
10	Muro da Prega (Beja)	WB/R	H=3.9 L=62 Th=6.2 Buttresses; Th=2 Spac=4.5	3	1750 m	Water supply and irrigation	Quintela et al; 1985
11	Hortas de Baleizão (Beja)	WR/R	H=1.1 L=120 Th=0.9	1	?	Irrigation	Quintela et al; 1985
12	Pisões (Beja)	WR/R	H=4.3 L=58 Th=3	18.6	200 m	Water supply and irrigation	Viana; 1947 Ribeiro; 1972
13	Muro dos Mouros (Serpa)	WB/C	H=3 L=130 Th=1.5 Buttresses: Th=0.5 Spac=6	0.7	375 m	Irrigation	Viana; 1950
14	Monte Novo do Castelinho (Almodôvar)	E/R	H=0.8 L=56 Th=11 (base)	0.3	300 m	Water supply and irrigation	Quintela et al; 1985
15	Álamo (Alcoutim)	WB/R	H=3 L=50 Th=3 (base) Butresses: Th=1.5 Spac=2.3	0.3	90 m	Water supply and irrigation	Santos; 1972
16	Santa Rita (Vila Real de Santo António)	DWB/R	H=2.2 L=50 Th=3.2 Buttresses: Th=1 Spac=6	0.3	?	Irrigation	Veiga; 1887 Santos; 1972
17	Fonte Coberta (Lagos)	WR/R	H=2.6 L=75 Th=2.6	1.9	1500 m	Water supply and irrigation	Sarrão Ca; 1960 Veiga; 1910 Santos; 1971
18	Vale Tesnado (Loulé)	WR/R	H=1.2 L=220 Th=0.7	37.5	1600 m	Water supply and irrigation	Paço and Farrajota; 1966 Santos; 1971
19	Represa* (Gavião)	DW/R	H=10 L=78 Th=2.3 (base) Earthfill between walls: Th=6.3	26.7	1800 m	Water supply and irrigation	Machado and Ferrinho; 1952
20	Monte Novo* (Évora)	WB/C	H=5.7 L=52 Th=6.5 Buttresses: Th=2 Spac=12	2.9	?	Hydropower	Pote; 1981

Structure:

Wall with a rectangular section: WR
Wall with downstream buttesses: WB
Wall with a downstream earthfill: WE
Double wall with an intermediate earthfill and downstream buttresses: DWB
Earthfill: E

Plan:

Rectilinear: R
Poligonal: P
Curvilinear: C

Dimensions:

Maximal visible or probable height: H
Length: L
Thickness: Th
Spacing: Spac

* Dams of unconfirmed Roman origin

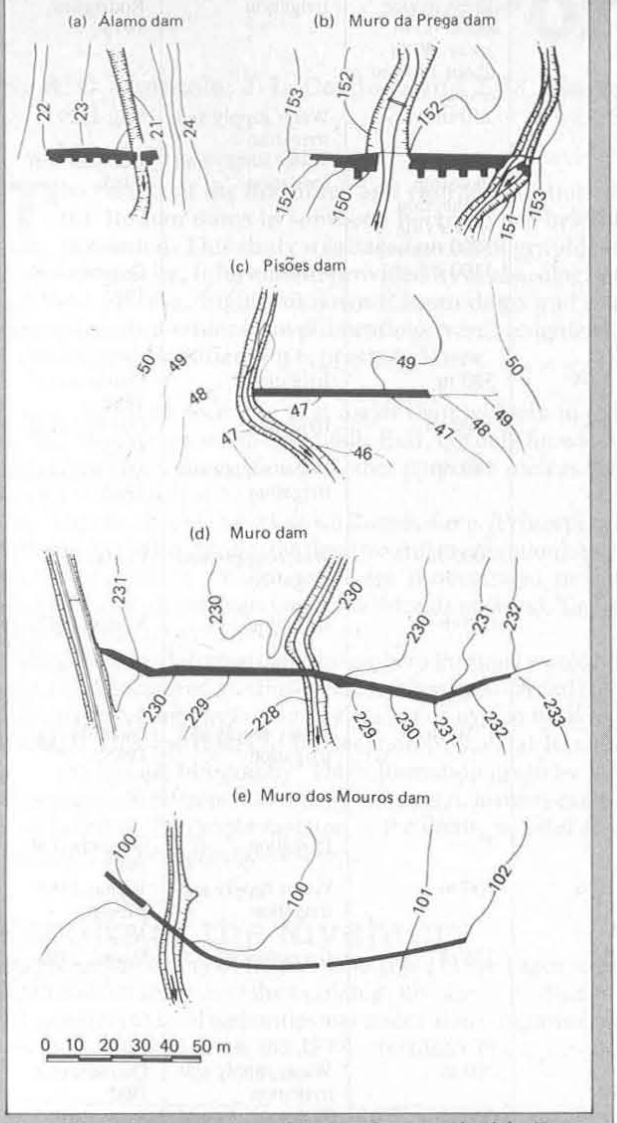

Fig. 2. Typical cross-sections of Roman dams south of the Tagus: a) Wall with a rectangular section; b) Wall with downstream buttresses; c) Wall with a downstream earthfill; d) Double wall with an intermediate earthfill and downstream buttresses.

without buttresses (Figs. 2 and 3). Studies of this type of dam show that the nucleus (juxtaposed layers) and the wall surface (lining blocks) were constructed simultaneously.

The only reliable exceptions to this type of structure are the Monte Novo do Castelinho dam, which is of the earthfill type, the Tapada Grande dam, with a stabilizing downstream earthfill, and the Santa Rita dam, with a double wall, an intermediate earthfill and buttresses placed downstream. The only other known Roman dam of this type is that of Ereruisk (Soviet Armenia), dating from the fifth century AD[3].

In three cases (Muro, Muro dos Mouros and Santa Rita), the upstream wall surface shows traces of mortar lining. Fig. 2 shows the typical cross-sections of the known dams, with the exception of the earth dam of Monte Novo do Castelinho.

It should be noted that some of the dams with buttresses (Muro, Nossa Senhora da Represa, Muro da Prega and Álamo), did not require buttresses for structural stability because the wall section is oversized. In Nossa Senhora da Represa, the buttresses do not contribute at all to the stability of the intermediate sections of the wall, because they are spaced too far apart.

The plan of the dams is rectilinear, polygonal or curvilinear

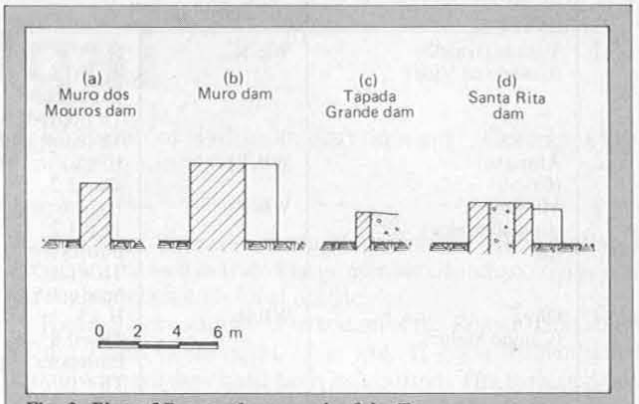

Fig. 3. Plan of Roman dams south of the Tagus:
— rectilinear plan (a), (b) and (c);
— poligonal plan (d); and,
— curvilinear plan (e).
(The deviation of the water stream in (a) and (c) can be observed.)

The Pisões dam: view from downstream, showing the partially preserved outside lining.

with a concave shape facing upstream (Fig. 3). None of the Roman dams which have been inventoried are in operation. This is because of openings which allow the water to pass through the dam or the deviation of the stream towards one end of the dam (Fig. 3).

The silting of the reservoirs is variable, depending on drainage basin erosion, as well as on the operational life of each reservoir and on further modifications in the thalwegs, already mentioned. The reservoirs of Olivã, Nossa Senhora da Represa and Muro da Prega are badly silted. The reservoirs had small or very small capacities. Topographic surveys of only six reservoir areas are available; their capacities, according to the present tops of the dams, are as follows:

- Muro dam: 178 000 m³
- Muro da Prega dam: 6200 m³
- Pisões dam: 80 000 m³
- Muro dos Mouros dam: 80 000 m³
- Álamo dam: 2100 m³
- Santa Rita dam: 13 200 m³

The Muro dam stands out among the others for its architectural characteristics and also for the technical solutions that were adopted. It has an outstanding height and size; it is the only case in which parallel and horizontal rows of large bricks are laid evenly, and arches between the buttresses which are subject to greater strains. The function of such arches was presumably to concentrate weight on the buttresses.

There is clear evidence of bottom or middle level outlets in the dams of Pisões and Muro dos Mouros. Pisões dam has at least one bottom outlet, made of a sluice in the wall, with a brick layer, showing the outline of perfect archways. In the wall of Muro dos Mouros dam, a certain distance up from the base, there is a pottery pipe, which was certainly used to discharge the stored water. The position of the bottom outlet of the Muro

(Continued on page 70)

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dam corresponds, no doubt, to the present thalweg. There were certainly bottom outlets in other dams, but they are no longer visible because of their poor state.

It should be noted that three earthfill dams have been found north of the Tagus: Rochoso, Idanha-a-Velha and Lameira. Only the second one has been recorded before[4]. The detailed study of these dams is of great interest, since of the earthfill dams so far discovered, only the masonry spillways survive[5].

□

Acknowledgement

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