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Dams from the Roman era in Spain. Analysis of design forms

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A recent academic study undertaken by the authors[1] (Castillo 2002; Castillo y Arenillas 2000) has enabled the identification of remains of and references to seventy-two dams from the Roman era, constructed in Spain between the first and fourth centuries.[2] Fifty of them have been located and detailed. The twenty-two outstanding, although identified on the ground, have not been able to be acceptably characterized, due in some cases to their being ruins in a highly degraded state, others due to their being masked by repairs and reconstructions subsequent to the Roman era. A list of the properly characterized dams is enclosed in the Appendix at the end of this paper, where reservoir dams are illustrated on the one hand (21) and diversion weirs on the other (29). The main dams (nearly all of them are large dams by present standards) are included in Table I.

Location and emplacement of Roman dams in Spain

Most of the dams built in Spain by the Romans —and particularly the largest ones— can be gathered together in three main areas: the basin of the river Ebro, especially the right bank, whose focus may be located in Zaragoza (*Caesaraugusta*); the area of Mérida (*Augusta Emerita*) along the basin of the river Guadiana, and the left bank of the river Tajo in some points near Toledo (*Toletum*). The natural regulation of the rivers flowing in these sections of the Spanish mainland is low or very low, basically as a consequence of the unequal distribution of annual precipitation (Arenillas 2000); these climatic conditions forced the construction of reservoir dams. In fact, four of these dams were constructed so as to ensure the water supply to the Roman towns

Tabla 1. Principal dams of the Roman era in Spain

NAME	HEIGHT	RIVER	BASIN
Almonacid de la Cuba	34,0	Aguasvivas	Ebro
Proserpina	21,6	Las Pardillas	Guadiana
Cornalvo	20,8	Albarregas	Guadiana
Ermita Virgen del Pilar	16,7	Santa María (Aguasvivas)	Ebro
Alcantarilla	15 to 20	Guajaraz	Tajo
Muel	13,0	Huerva	Ebro
Pared de los Moros	8,4	Farlán (Aguasvivas)	Ebro

mentioned above: Muel to *Caesaraugusta*, Proserpina and Cornalvo to *Augusta Emerita*, and Alcantarilla to *Toletum*.

However, this system was not the standard pattern applied by the Romans to resolve supply problems. In reality they only used it when, with good reason, climatic conditions forced them to do so.[3] In most cases (and frequently in Spain) they opted for riverhead collections by means of diversion weirs or intakes direct from sources.[4]

Nevertheless, when the Romans built regulation dams in Spain they frequently differed from this pattern. Of the three areas aforementioned this can be found in the basin of the Ebro (area of *Caesaraugusta*) where large dams were located, as a rule, in the middle stretch of rivers of some importance. On the other hand, in the mid-west of the Peninsula (*Emerita* and *Toletum*) these works were always situated on riverheads or streams with small catchment basins.

These differences of criteria regarding the emplacements can also be found in the structural solutions adopted: in the Ebro the highest dams are masonry dams, whilst in the Tajo and Guadiana the dams are earth dams with retaining walls upstream. However, the smallest dams —where other forms may be found— form a more homogeneous group in general.

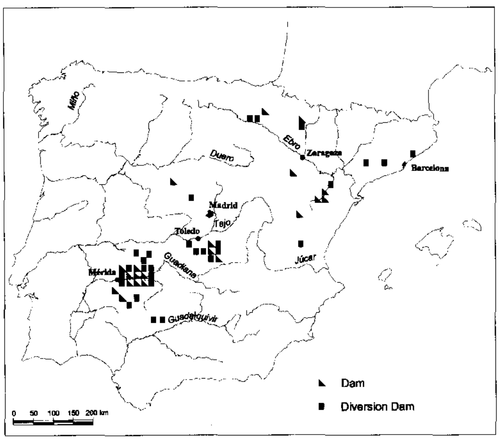

Figure 1
Location of the dams in the Roman era

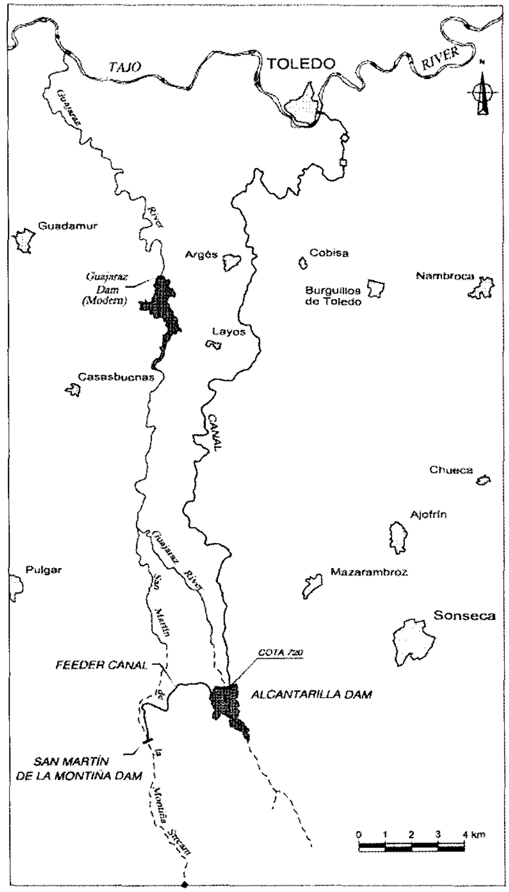

Figure 2
Supply system to *Toletum* (Alcantarilla dam)

STRUCTURAL FORMS

In the majority of the dams built in Spain by the Romans there is a basic characteristic construction element, almost systematically repeated: the retaining wall, used to achieve watertightness of the structure. Other elements, though not always, were added to ensure or complete the stability of the system. The Roman retaining wall is a very simple concept: a lime concrete core (*opus caementicium*), framed by two wall sections made of masonry (*opus incaertum*) or ashlar (*opus quadratum*). When the masonry was of poor quality other wall sections were attached to the first ones being of increasingly better quality towards the exterior. The most important element of this system was the core of *opus caementicium*, whose purpose was to comply with the objective of retaining the water.

The large dams on the Ebro basin

The dam which probably conforms best to the strict pattern of retaining wall is the one known as La Pared de los Moros (The Moors' Wall).[5] It is located near Muniesa (Teruel) in a secondary waterway, the Arroyo Farlán, the rightward tributary of the river Aguasvivas,[6] which at the same time is a branch of the Ebro, also on the right bank (Arenillas, Díaz-Guerra y Cortés 1996). The dam initially formed a reservoir of approximately 150,000 cubic metres capacity; nowadays it has a breach in its middle section. The characteristics of the masonry —not properly laid down in general, and the layout— somewhat winding (as with the layout of the limestone outcrops in the area) enable us to think of it as a later Roman work of rural style, perhaps dedicated, at least in part, to irrigation. The structure is nearly 8,5 metres in height and has a crest length of around seventy metres. Its form is as previously indicated: a single wall of nearly three metres thickness, formed by two masonry wall sections laid with lime mortar (*opus incaertum*) and a core of *opus caementicium*. The coverings are of 1,10 metres thickness each and are built with local limestone, lightly worked. The core reaches up to seventy centimetres thickness.

The basic fault of this structure is its extreme thinness[7]. With such a risky geometry the presence of an earth embankment downstream should be expected, but the materials existing there have not permitted the detection of the remains of such a complementary structure. As a result, the Pared de los Moros undoubtedly broke, and probably quite early as the sediments of the reservoir have not developed much, although they also could have been swept away by the waters after the dam breached. They can be observed, in particular, on the right bank where they show up without excessive re-workings —natural or artificial— since their deposition.

The calcareous concretions observed in the downstream face of the dam are not abundant, which could indicate that the retaining wall worked properly from the point of view of impermeability. In fact, the *opus caementicium* forming its core is of good quality.

The best pattern of a dam formed by a reinforced retaining wall (that is, an improved version of the previous pattern in terms of resistance) is the dam of Almonacid de la Cuba[8]. This is the highest dam from the Roman era preserved in the world (thirty-four metres). It is located on the river Aguasvivas and has a catchment basin of about 1.000 square kilometres. Built in the era of Augustus and rebuilt and repaired several times, this dam has a peculiar feature which makes it even more interesting: the preserved structure is an important reconstruction of a previous structure of completely different form.

The first dam raised on the closure site of Almonacid must have been formed by three arches,

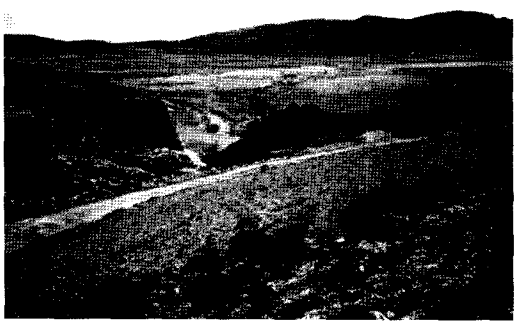

Figure 3
La Pared de los Moros

Figure 4
Dam of Almonacid de la Cuba

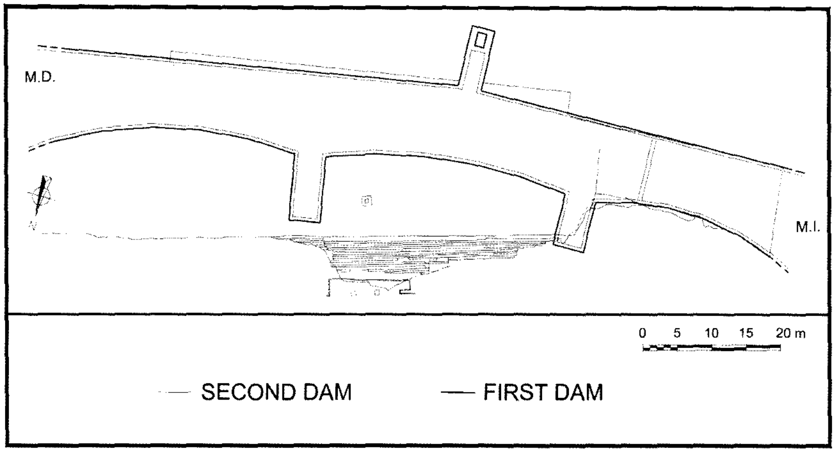

Figure 5
Layout (assumingly) of the early dam of Almonacid

one central and two side ones leaning against two large buttresses (Arenillas, Díaz-Guerra y Cortés 1996). This first dam must have been breached quite early, even perhaps in the later phases of construction and it also must have been rebuilt at once, its original structure being substantially modified, becoming the typical straight gravity dam. The breach of the dam was certainly partial and probably was located on an isolated point, the central arch for example, as in the latter reconstruction many of the original elements were entirely or partly preserved: the arch of the left edge, with elements from the buttress it was leaning against, or the intake tower, among others (Arenillas, Díaz-Guerra y Cortés 1996; Hereza et al 1996).

The first dam of Almonacid has been dated by the C14 method applied to two wooden samples obtained in a drilling. The age calibrated for those samples dates the construction of this work to the era of Augustus and, particularly, in the early years of the first century A.D. Therefore the second dam belongs most certainly to the first decades of the same century and, perhaps even to the very era of Augustus (Arenillas, Díaz-Guerra y Cortés 1996).

The definitive dam of Almonacid is a retaining wall, highly reinforced in its main part, with a thinner, short block on the left edge, where the weir is. The main part of the structure —very robust— encloses the deepest area of the valley and consists in section of a rectangular central body and two stepped faces; downstream the stepping is double. In the central body a retaining wall stands out which, according to the data obtained from the drillings, reaches between 10 and 12 metres thickness, of which the 2,70 central metres belong to a lime concrete core (*opus caementicium*). This core is framed between two double masonry wall sections (*opus incaertum*) with an average thickness of about 3,70 metres upstream and 4,60 metres downstream. In both cases the masonry located beside the core is of worse quality than the exterior ones.

The retaining wall belongs to the first dam and perhaps then had an ashlar facing (*opus quadratum*), as may be deduced from the samples obtained in some drillings. This wall was considerably reinforced on reconstruction: a masonry wall of about 9 metres thickness was built downstream, covered on the face by a wall section of *opus vittatum* (limestone pieces placed in horizontal courses) where a large stepped-in skirt was attached, the lower of the two preserved on that side. The reinforcement would be increased later on with two new stepped-in skirts, one on each side.

After this major reconstruction and as a consequence of the repeated effects of the floods on the river Aguasvivas, the dam had to be continuously repaired. In the preserved masonry various reconstructions can be observed and from the study of

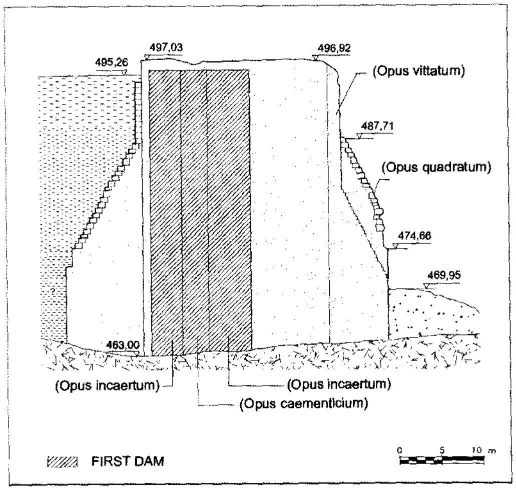

Figure 6
Dam of Almonacid. Section

Figure 7
Dam of Muel

the reservoir deposits a period of abandonment during the second half of the first century has been detected (Hereza et al 1996). The most important works can be dated to the era of Claudius (41–68) and Trajan (98–117) (Arenillas, Díaz-Guerra y Cortés 1996). In the latter period the dam was heightened in order to alleviate silting effects, which must have been significant (Hereza et al 1996).

Thanks to these measures and the later silting of the reservoir, the dam has been preserved to date after some medieval and later works by which time the dam had already become a diversion dam. It still complies with this function, diverting the waters through the former Roman canal up to the irrigation area of Belchite, located approximately 8 kilometres downstream.

The second structure designed by the Romans in the straight of Almonacid may definitely be considered as valid —although excessive by present criteria— from a resistance point of view. The almost 40 metres thick foundations as opposed to 34 metres maximum height assured this condition. And yet in any case the Romans did not deal properly with two important matters: firstly the weir, with an obvious lack of capacity to cope with the main floods.[9] Secondly the poor quality of the lime used to build the retaining wall core. The first of these faults may explain the cause of the major reconstruction of the first dam and the various later repairs. The second has been checked according to the samples obtained from the drillings, where in some cases the lime of the *opus caementicium* core of the retaining wall is observed to be unset at many points. This fact certainly led to the lack of general impermeability of this fundamental building element, as may be deduced from the many calcareous concretions appearing on the downstream face of the dam, particularly on the wall section of *opus vittatum*.

Two other important dams on the basin of the Ebro are Muel and La Ermita de la Virgen del Pilar. The first is of great interest as it belongs to one of the three (or four) Roman supply systems to *Caesaraugusta*. However it has not been researched in detail since it is not an easy task due to the fact that the reservoir which it formed on the river Huerva (branch of the Ebro on the right bank) is completely silted up. Nevertheless, the facing masonry downstream can be seen at a height of about 13 metres. This masonry is made of dressed ashlar with courses about 50 cm in height. The majority of the ashlars are laid in stretcher courses, though some are placed in header courses. The masonry thickness has been sized at around 7 metres (Castillo 2002) although it could be thicker in the lower part of the work. Its internal structure is not known and, although there are filtrations through the face, it seems reasonable to think of some waterproof element inside (a core of *opus caementicium* for example). The dam could have been easily built in the era of Augustus, as it is related to the water supply to *Caesaraugusta*, and perhaps at an early date, for the facing masonry would fit this period.

The dam of La Ermita de la Virgen del Pilar on the river Santa María, tributary of the Aguasvivas, is a gravity dam formed by a complex retaining wall built in two stages. Only the part of the structure located at the highest point of the left edge is preserved, where a heterogeneous succession of masonry can be observed, allowing the explanation of two-stage construction and also the final heightening of the structure. However the total thickness of the dam is only 6,90 metres, which for its maximum height of 16,60 metres shows a clear situation of instability. In fact the dam collapsed, though not very early, as the reservoir sediments grew quite thick, as may be observed on the slope upstream from the dam. According to its structure it could have been built following the model of Almonacid, although the masonry quality is remarkably poorer. In any case the height of this work is surprising (taking into account the Roman standards) as is its function, as no reasonable destination has been traced for its waters (Confederación Hidrográfica del Ebro —Ingeniería 75 2000).

Figure 8
Dam of la Ermita de la Virgen del Pilar

The large dams on the basins of the Tajo and Guadiana

Also in the large earth dams in the mid-west of the peninsula the retaining wall was used as a fundamental element to retain the waters. In two cases (Alcantarilla and Proserpina) this solution was applied with very strict design criteria; as for the other (Cornalvo) a more complex variant was resorted to, although in this case the work preserved (being originally Roman) possibly shows important alterations from later eras.

The first of these dams must be that of Alcantarilla (Arenillas et al 1999), which has been in ruins since early times, probably since the Roman era. The causes of this breach have been analysed starting with the numerous remains preserved and thanks to its similarity to the dam of Proserpina. The dam is located on the river Guajaraz, tributary of the Tajo on the left, on a high level of its course (with only 50 square kilometres of drainage area) and it was the head of the important Roman water supply to Toledo (Fernández 1961; Celestino 1976; Sánchez 1977; Aranda, Carrobles e Isabel 1997; Arenillas et al 1999). The dam is formed by a large earth embankment (highly degraded today) and by a retaining wall upstream, of which some traces are preserved almost intact and various blocks strewn over the ground. The maximum length of the dam must have exceeded 800 metres and its maximum height may be estimated as between 15 and 20 metres. The embankment is formed by sandy clays typical of the altered granites of the basin and hence, is unlikely to be highly impermeable; consequently the retaining wall again carries out the function of avoiding the passage of the reservoir waters, leaving the resistance action to the embankment as the retaining wall is very thin for its height, about 4 metres thick at its base.

As observed in some blocks, the retaining wall is formed by a lime concrete core (*opus caementicium*) of about 60 centimetres thickness, manufactured with small pebbles (*caementa*), 5 cm maximum, and a great deal of aggregate. The core is situated between two masonry wall sections (*opus incaertum*) of variable thickness, oscillating between 90 cm and 1,50 metres. The upstream wall section must have been composed wholly of ashlar stretcher courses (*opus quadratum*) of which some course traces are preserved in the block that stands on the left edge. They are fine worked pieces of about 50 cm height, 60 cm thickness and lengths reaching over one metre. The downstream face follows the vertical line, whilst the upstream face is slightly separated from it.

The main problem —well known nowadays— of a dam of the above characteristics is its instability at empty reservoir: a retaining wall as thin as the one of

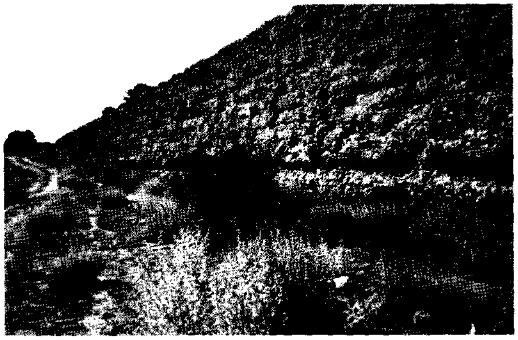

Figure 9
Dam of Alcantarilla

Figure 10
Dam of Proserpina upstream

Alcantarilla hardly resists the embankment push in those circumstances and least of all when it is saturated, a situation which may arise from filtrations through the retaining wall or from overspills on the crest. In fact the dam was breached due to the embankment push, as the retaining wall is strewn towards the reservoir in the ruined middle portion, although some elements show up downstream; the position of the latter can be explained by movements during flood episodes after the breach. Nevertheless, the dam is likely to have breached during a flood, as most certainly (along with Cornalvo and Proserpina) it was not provided with a weir.

In the dam of Alcantarilla there are still remains of two intake towers, one on the lowest point of the closure and the other located on the right bank and therefore, at a higher position than the previous; both were attached to the retaining wall downstream. In the central tower the intake must also have functioned as a dewatering outlet, as the whole reservoir could not be emptied from the other tower; it is the same pattern found in Proserpina.

In summary, the form adopted by the Romans in the dam of Alcantarilla was, in principal, correct but they did not count on two important factors: the floods of the Guajaraz and the lack of resistance of the retaining wall to the embankment push at empty reservoir. In Proserpina, whose structure follows the same form, some improvements were made; this happened also in Cornalvo. Hence, Alcantarilla is likely to be the most ancient of the three large Roman dams preserved in the mid-west of the Peninsula (Arenillas et al 1999).

The dam of Proserpina is a much better known work than the above as it is still working (although dedicated to aims other than those intended by the Romans) and has recently been studied (Arenillas, Martín y Alcaraz, 1992; Alcaraz et al, 1993; Confederación Hidrográfica del Guadiana-Ingeniería 75, 1996; Martín et al, 1998). It is located on the course of the brook of Las Pardillas, a sub-tributary of the Guadiana on the right bank..

In 1991 the Confederación Hidrográfica del Guadiana (Water Management Administration) started a series of activities for the refurbishment of the dam and the regeneration of the reservoir, whose waters had reached a high degree of eutrophication and could not be drained, as the deepest outlets —the original Roman intakes— had lost their function due to the partial silting up of the reservoir. The removal of these materials revealed nearly seven metres of masonry whose morphology contrasts to some degree with that of the upper part of the structure, the one known up to that date. This activity and the data obtained from several drillings and other investigations carried out, enabled a good evaluation of the structure.

The dam of Proserpina is formed by a masonry wall (the retaining wall) to which an earth embankment is attached downstream. The retaining wall is formed by two granite masonry wall sections —ashlar, banded stone or masonry, depending on the areas— with a core of lime concrete between them. The maximum height of this wall is of 21,60 metres of which the lower 6,60 metres belong to the recently discovered masonry. In layout the dam follows three straight alignments with a total crest length of 427,80 metres. On the left edge there is also an auxiliary wall

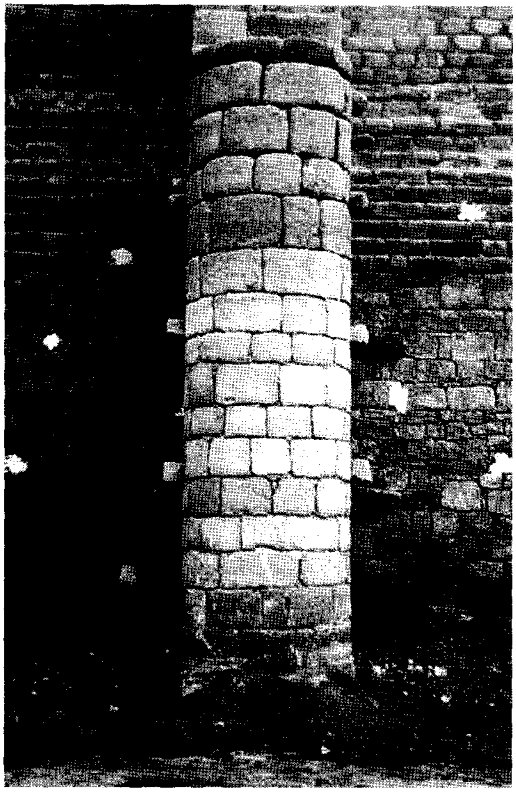

Figure 11
Dam of Proserpina. Detail of a buttress

of about 100 metres length used to enclose some areas where the ground remains below the crest of the dam.

The upstream face of the retaining wall is vertical in the lower 6,60 metres and inclined in the rest, which can be achieved by the stepping of successive ashlar courses forming it in that area. Nine buttresses emerge from this face, distributed irregularly along the central sector of the dam; eight of them have their origin in the lower masonry. These eight buttresses are vertical in the part belonging to the oldest masonry and from that area they extend up to the crest with a gentler slope than that of the wall, achieved similarly by offsetting the successive courses. In the lower section these buttresses finish with a semicircular section at about 4,5 metres from the face; in the upper stepped area all the nine buttresses are of rectangular section.

The downstream face remains covered by the earth embankment almost up to the crest. Nevertheless its verticality has been proved by means of drillings and scrapings in several points and probably is a general characteristic throughout the structure. The indicated probing permitted the detection of sixteen buttresses in the middle section of the dam. They are vertical masonry elements of approximately 1,40 metres width and three metres length, split about six metres between each axis. All the buttresses finish two metres below the crest, just where a 30 cm ledge is located, which shows up along the face of the dam. The horizontal drillings made in the retaining wall have indicated a foundation thickness of 5,90 metres.

The reservoir intakes are placed in two towers attached to the retaining wall in its downstream section, therefore embedded in the earth embankment, and emerging at a height so as to allow access. The main tower is located on the deepest part of the closure site and has an irregular section, although almost square, of about 5 or 6 metres on its exterior sides. This tower contains two intake series. The lower (of the Roman era) is formed by two lead pipes of about 22 cm interior diameter, placed at more than three metres over the foundation level. Nearly four metres higher up there is another intake cut into a granite flagstone which probably belongs to works from the seventeenth century. The other tower is located on the left bank at about ten metres over the river course. It also has a slightly square section of about 7 metres on the exterior sides. This tower contains an upper intake, located nearly twelve metres above the lower one. Until the 1940's the Roman pipe must have been preserved, being later replaced by the cast pipe presently in existence.

This intake is particularly interesting: it is the only one which by level allows the transfer of water from the reservoir to Mérida across the bridge of Los Milagros as the level of the conduit above this aqueduct is higher than the level of the other Roman intake. This fact assures the Roman character of all of the dam[10], although this does not exclude the subsequent repair or reconstruction of the upper section of the structure. On the other hand, some absolute dates are provided for the dam of Proserpina from two wood samples obtained from the lower part of the masonry by means of a horizontal drilling. Analysed by the C14 method they enable the dating of the construction of this masonry to the era of

Figure 12
Dam of Proserpina. Roman intakes

Figure 13
Aqueduct of Los Milagros

Trajan (98–117) (Confederación Hidrográfica del Guadiana-Ingeniería 75 1996). Therefore it seems reasonable that the construction of the aqueduct of Los Milagros should be dated to the same period or even somewhat later.

The dam of Proserpina, with a similar structure to that of Alcantarilla (although reinforced with buttresses) has outlived the latter almost two thousand years. It is not clear, however, that such measures have played a part in the longevity of the structure, since the upstream buttresses (probably built in order to improve the resistance of the retaining wall against the push of the embankment at empty reservoir) do not seem to be too effective as a result of the distances between them.[11] The reason for the stability of the retaining wall must be basically the low probability of important floods on the small stream feeding the reservoir (with a basin of 8,5 square kilometres) even adding the effects of the contiguous basin, from which flows were transferred to the reservoir (another 15 square kilometres)[12]. This practice ensures greater flows in normal circumstances, but at the same time enables their elimination by stopping the transfer under extreme circumstances. This is surely the reason why the dams of Cornalvo, Proserpina and Alcantarilla were not provided with weirs,[13] for the outlets must have been considered sufficient to handle the respective reservoirs. This assumption turned out to be valid in Proserpina and Cornalvo but not in Alcantarilla, where the catchment basin is somewhat larger.

The Roman dam of Cornalvo is located on the river Albarregas, tributary of the Guadiana on the right bank, about fifteen kilometres from Mérida. It was built in order to improve the previous exploitation of the water supply to *Emerita*, which had its origin in a series of collection galleries tunnelled into the deposits of the river Albarregas, in the area later flooded by the reservoir.(Martín et all 2000). These galleries converged at one point (Macías 1929) where the conduit towards Mérida started. The dam must have been built when the water from this source proved to be insufficient for the town; then an intake tower was raised at the spot where the former galleries met, near the dam but inside the reservoir. Therefore the Cornalvo intake tower turns out to be a unique element in the dams from the Roman era built in Spain.

The dam of Cornalvo is not yet properly researched, but it mainly follows the pattern of Alcantarilla and Proserpina: a large embankment sheltered upstream by a structure element —not exactly a retaining wall— which carried out the function of preventing the passage of water. From the data available today it seems that this structure is formed by three longitudinal walls (parallel to the direction of the dam), another series perpendicular to the latter and all of them covered by the face upstream of the dam, which has a gently rising slope. The enclosures formed by this group of walls are filled with materials of different types.

It is not clear whether this system was adopted by the Romans, for it would be quite an innovative pattern for that era, at least in Spain. It is possible though, that the Romans just built a wall alongside the embankment —perhaps a retaining wall in this

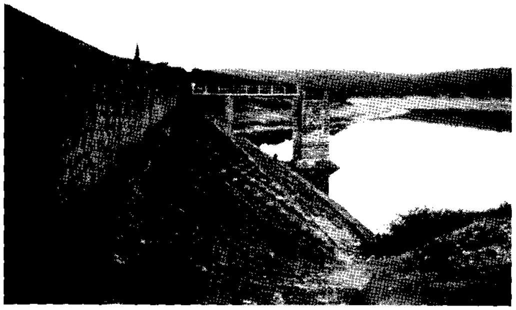

Figure 14
Dam of Cornalvo

case— and that they reinforced it somehow, questions that must be answered once the structure has been fully researched. It is known that the dam has been repaired in several occasions and hence, it is possible that part of this structure belongs to some of these activities.[14]

Small Dams

On small works (Appendix) the Romans quite frequently maintained the forms followed for the large dams, but in many occasions they simplified these structures and even adopted different ones. For example, the standard retaining wall was replaced in many cases by a simple wall of *opus incaertum*. Therefore the water leakage would surely be greater than that resulting from the masonry of *opus caementicium*, but obviously the problem could be acceptable for most of the diversion weirs, as well as low height dams. There is one case (dam of El Paredón) and perhaps more, where the Romans tried to solve this problem by adding a mortar rendering to the upstream face. In this dam the rendering is, essentially, an *opus signinum* like the one used by the Romans to dress and water-proof canals and tanks (Castillo 2002). On small dams the pattern of an earth dam with retaining wall upstream is also used, in some cases with the required buttresses upstream, as can be observed in Las Tomas (Guadiana) or El Paerón I (Tajo). A very common solution in these structures also is the buttress dam, formed by a retaining wall, a simple wall or multiple arches, leaning against the buttresses, located downstream. The best example of this type may be, due to its importance (over 600 metres length, although only 4,80 metres height) the dam of Consuegra, on the basin of the Guadiana. It had a retaining wall upstream, numerous buttresses and perhaps an embankment downstream, of which no remains are left. (Castillo 2002). Similar to this dam but with no embankment is the dam of Araya, and with multiple arches the dam of Esparragalejo, both near Mérida. On the Ebro basin the dam of Villafranca (150 metres length and a reduced height of 3 metres) is the most notable of this type.

An original form, as we only have one example, is the gravity arch dam. To this type belongs the dam of Puy Foradado in the important hydraulic system of Los Bañales (Ebro basin). It is a circular structure, with approximately 56 metres of development and reduced height (about 2 metres) used as diversion weir in the mentioned system. The upstream face is formed by four ashlar courses; it is the only visible masonry nowadays, since the reservoir is completely silted-up (Castillo 2002).

One last dam also to bear in mind, for its structure is somewhat peculiar, is the dam of Iturranduz, at the head of the Roman water supply to the town of Andelos (Ebro basin). It is a double dam, or rather duplicated, as two structures have been preserved, one probably from the second century, the other posterior (third or fourth century). The eldest is located downstream from the other and it was a wall of over 100 metres length, nearly one metre thick and a little more than four metres in height (as per the remains

Figure 15
Dam of Consuegra

preserved) leaning downstream against nine square section buttresses with 2,50 metres side length. All the masonry is made of lime concrete (*opus caementicium*) and the traces of the wooden formworks used for its construction can be observed in it. The second structure is a simple wall with buttresses too, but in this case such elements were located upstream. The length of this wall is greater than the previous one (about 150 metres) and the thickness is less (65 cm); its height is not easy to estimate, but it could not have exceeded the other structure. The wall leans against an uncertain number of buttresses, which, according to the remains could be more than fifteen. In this case the masonry is bedded with lime mortar and laid in courses (perhaps, *opus vittatum*). By its position on the ground this second structure must have been designed as a reinforcement or repair of the first, as the space between them must have been filled with earth (which was extracted when the area was being excavated). Some remains of an intake tower are preserved in this second dam, where the conduit towards Andelos must have started.

Figure 16
Dam of Iturranduz (inferior)

Auxiliary elements of the dams

The lack of weirs is one of the characteristics —anomalous we would say nowadays— of nearly all the Roman dams located in Spain. Only in Almonacid may work of this type be clearly identified. However, and as stated above, its capacity was very low and therefore, hardly effective. It is also true, as far as we know today, that the Romans never built dams on large plentiful rivers and most of the time they simply intercepted minor streams. Accordingly, it is possible that the Romans really intended, in those cases, the formation of large deposits at the heads of the hydraulic systems they built (*caput acquae*). In this manner they could control the reservoirs on low flow watercourses and during small floods by simply using the outlets installed in the dams. But in Spain, in rivers like Aguasvivas (Almonacid), Huerva (Muel), Guajaraz (Alcantarilla) or even Santa María (Virgen del Pilar), circumstances were certainly distinct; despite none of these rivers being especially plentiful (although their floods can be considerable). However, not even in those cases did the Roman tackle the problem adequately. In some masonry dams the floods did not manage to cause ruin to the structure (second dam of Almonacid or Muel) but, logically, the same cannot be said of the earth dams (Alcantarilla). Probably due to this fact the latter form was only repeated in other dams located in areas where the probability of large floods was very low (Cornalvo and Proserpina, among the largest works).

Other interesting elements are the intake towers built by the Romans, systematically as it seems on the large dams, but also on smaller ones. In all known cases, except in Cornalvo, these works were attached, upstream or downstream, to the masonry of the structures, with access from these or from the embankments to the chambers where the opening and closing elements of the conduits were located (almost always bronze pieces on lead pipes). The breakage or breakdown of these elements must have caused complicated problems; as such situations should lead systematically to the flooding of the tower by the reservoir water. In Proserpina, when the sediments that had partially filled the reservoir had been removed, a large wooden plug was found (dated to the Roman era by C14) that must have been used to close the conduit from the reservoir in this kind of event. In these cases the problem must have been the removal of the plug under a full reservoir.

APPENDIX. Reservoir dams and diversion weirs from the Roman era in Spain

NAME	DIMENSIONS			SITUATION			TYPE	DATE CONST.
	L	T	H	RIVER	BASIN	PROVINCE		
RESERVOIR DAMS								
Almonacid de la Cuba	120,0	38,0	34,0	Aguasvivas	Ebro	Zaragoza	RRW	I
Proserpina	427,8	5,9	21,6	Las Pardillas	Guadiana	Badajoz	E (RW)	I–II
Cornalvo	194,0	26,0	28,0	Albarregas	Guadiana	Badajoz	E (RW)	I–II
Alcantarilla	>800,0	4,0 (?)	20,0	Guajaraz	Tajo	Tolero	E (RW)	I
Ermita de la V. del Pilar	80,0	6,9	16,6	Sta. María	Ebro	Teruel	RRW	I–II
Muel	60,0	7,0 (?)	13,0	Huerva	Ebro	Zaragoza	RRW	I
La Pared de los Moros	68,0	2,7	8,4	Farlán	Ebro	Teruel	RW	III
Esparragalejo	320,0	2,2	5,6	Albucia	Guadiana	Badajoz	B (RW)	I
Consuegra	>632,0	2,6	4,8	Amarguillo	Tajo	Toledo	B (W)	III–IV
Las Tomas	95,0	1,9	5,2	—	Guadiana	Badajoz	B (W)	IV
Iturranduz o Andelos inf.	102,0	1,0	>4,0	San Pedro	Ebro	Navarra	B (W)	II–III/IV
Iturranduz o Andelos sup.	150,0	0,7	(?)				B (W)	
Arévalo	50,0	3,0	6,0 (?)	Arevalillo	Duero	Ávila	DW	II
El Paredón	141,1	2,7	4,5	Paredón	Guadiana	Badajoz	E (RW-B)	III
La Pesquera	100,0	5,6	4,0	—	Ebro	Zaragoza	W	?
Araya	139,0	1,8	3,7	—	Guadiana	Badajoz	B (RW)	II
Vega de Sta. María	97,8	3,5	3,6	Heras	Guadiana	Badajoz	B (RW)	?
Villafranca	150,0	2,2	3,0	Jiloca	Ebro	Teruel	B (RW)	II–III
Paerón I	80,0	1,2	2,4	Sta. María	Tajo	Toledo	E (W-B)	I–II
Los Paredones	80,0	2,5	>2,0	Gitano	Guadiana	Badajoz	W	I–II
El Peral	30,0 (?)	1,0 (?)	2,2 (?)	Norias	Guadiana	Badajoz	W	I–II
La Cuba	52,0–180 (?)	0,8	>2,0	Cuba	Guadiana	Badajoz	E (W)	II–III
DIVERSION WEIRS								
Río Frío	13,4	0,7	1,1	Aceveda	Duero	Segovia	W	I
Pont d'Armentera	35,0	0,8	1,5	Gayá	Tarragona	Ebro	W	II–IV
Azud de los Moros	40,0	0,7	0,9	Tuéjar	Turia	Valencia	W	I
Arroyo Bejarano	40,0	2,0	3,5	Bejarano	Guadalquivir	Córdoba	W	I
Palomera Baja	15,0	1,0	2,2	Palomera	Guadalquivir	Córdoba	W	III
Puy Foradado	56,0	1,0	2,0	—	Ebro	Zaragoza	A (W)	II–III

APPENDIX. RESERVOIR DAMS AND DIVERSION WEIRS FROM THE ROMAN ERA IN SPAIN (continuación)

NAME	DIMENSIONS			SITUATION			TYPE	DATE CONST.
	L	T	H	RIVER	BASIN	PROVINCE		
Pineda o Ca'La Verda	25,0	1,5	2,5	Pineda	Ebro	Barcelona	RRW	III
Las Adelfas	(?)	(?)	(?)	Las Adelfas	Guadiana	Badajoz	W	II
Las Muelas	200,0	3,4	3,0	Las Muelas	Guadiana	Badajoz	B (RW)	II
Cañada del Huevo	100,0	5,0	2,5	—	Guadiana	Badajoz	B (RW)	II
Las Mezquitas	(?)	(?)	1,6	—	Guadiana	Badajoz	RRW	II
S. Martín de la Montiña	(?)	(?)	3,0 (?)	San Martín	Tajo	Toledo	W	I–II
Odrón y Linares	(?)	(?)	(?)	Odrón-Linares	Ebro	Navarra	W	?
Arroyo Salado	50,0	2,0	7,0	Salado	Ebro	Navarra	RW	?
Melque VI	19,5	2,5	4,5	Las Cuevas	Tajo	Toledo	RW	?
Charca de Valverde	170,0	3,0	>3,0	La Charca	Guadiana	Badajoz	E (RW-B)	?
Azud de la Rechuela	29,0	3,0 (?)	3,0	Aguasvivas	Ebro	Zaragoza	B (RW)	?
Les Parets Antiques	30,0	2,3	3,0	Riera S..Sebastián	Ebro	Barcelona	W	III–IV
Mesa de Valhermoso	98,0	1,8	3,0	Valhermoso	Tajo	Toledo	E (RW-B)	II–III
Castillo Bayuela	30,0	1,5	3,0	Guadamera	Tajo	Toledo	B (RW)	II–III
Moracantá	40,8	1,9	2,1	Guazalote	Tajo	Toledo	RW	I–II
El Hinojal (Las Tiendas)	230,0	1,6	1,3	Rto. Charcoblanco	Guadiana	Badajoz	B (RW)	III–IV
Paerón II	30,0	1,1	>1,5	Sta. María	Tajo	Toledo	B (RW)	I–II
El Argamasón	14,7	1,4	1,3	Tripero	Guadiana	Badajoz	RW	II–III
Balsa de Cañaveral	30,0	2,4	1,2	—	Tajo	Cáceres	E (W)	IV
El Peral II	7,6	0,7	>0,9	Las Norias	Guadiana	Badajoz	B (RW)	?
Valencia Ventoso	60,0–80,0	1,6	>0,8	—	Guadiana	Badajoz	W	III–IV
El Chaparral	50,0	1,1	>0,8	La Alcazaba	Guadiana	Badajoz	W	III–IV
Monroy	(?)	(?)	(?)	—	Tajo	Cáceres	W	?

RW: retaining wall; RRW: reinforced retaining wall; W: simple wall; DW: reinforced wall; E: earth dam; B: buttress dam; A: arch dam
L: crest length; T: thickness(in earth dams refers to thickness of the wall) H: maximum height

A tower of unique form, already referred to, is that of Cornalvo, located inside the reservoir. The operations performed from it are not easy to understand (with the means the Romans had to hand). This is why, most probably, it was a decorative element that may have been used to protect the beginning of the conduit, for the opening and closing operations could be done from inside the dam or immediately downstream.

NOTES

1. This is a doctoral Thesis, undertaken by the second undersigned and co-directed by the first in cooperation with Professor F.Santos (Castillo 2002).
2. Among these dams the diversion weirs of mining character have not been accounted for, though they are particularly numerous in the former Roman prospects —and previous ones— of the north-west of the peninsula, dedicated to gold extraction.
3. According to the data available, the large regulation dams built by the Romans are exclusively located in the Mediterranean areas poorly favoured with precipitation: Southern France, Hispania, North Africa and Middle East (Cf. Schnitter 1994).
4. In the Baetica province alone of the Spanish Peninsula 26 towns with water supply from the Roman era have been mentioned, and in this environment no important regulation dam seems to have been built since (Castillo 2002).
5. Up to recent times in Spain all *the ancient*, with no established or approximate date was said to be «from the Moors», that is, from the period of Muslim occupation. Lately, with greater levels of information and many more «experts» giving opinions over ordinary people, almost all *the ancient* has turned out to be «from the Romans».
6. In the basin of the river Aguasvivas there is a remarkable accumulation of dams and weirs, whose construction extends from the Roman era (with three — or four— structures) until the twentieth century and counts some interesting examples from the fourteenth to sixteenth centuries. (Arenillas, Díaz-Guerra y Cortés 1996).
7. For a rectangular section structure and average specific weight of 2 t/m3 (which must be equivalent to that of the Roman masonry), the strict tilting stability is achieved with a height double the thickness considering, logically, the effect of uplift, which very probably the Romans did not know how to value, in spite of Archimedes.
8. The date of construction of this dam, which had not been entirely researched until the 1990's (Arenillas, Díaz-Guerra y Cortés 1996), has been assigned many times to the Muslim era and even, in more detail, to the reign of Jaime I of Aragón (thirteenth century), according to the tradition of the eighteenth and nineteenth centuries. And this despite the fact that Ponz ([1788] 1989) had already written that «It seems to be from Roman Times but is attributed to King Jaime I who may have repaired it» and Galiay (1946) who later reiterated its Roman origin. Even Norman Smith, some years after Galiay, insists on placing the dam in the era of Jaime I in an extensive work concerning ancient Spanish dams that unfortunately contains some inexplicable errors.
9. In the aforementioned doctoral thesis (Castillo 2002) the calculation of these effects is included and it is demonstrated that the weir only has the capacity to clear less than twenty year return period floods. That is to say, during the first century A.D. (from Augustus to Trajan) and later, of course, the reservoir must have spilled over the crest on numerous occasions with the consequent erosion at the dam foot
10. The Proserpina dam has always been considered Roman since the time of first investigations. However, when the lower section of the work was discovered there were some opinions — not written, as far as is known — which began to doubt the Roman origins of the upper section of the structure.
11. As pointed out by C. Fernández Casado (1961). In addition, recent calculations show that the retaining wall would not be stable at empty reservoir and saturated embankment (Castillo 2002).
12. In Proserpina, Alcantarilla and Cornalvo diversion weirs were built on the courses of adjacent basins and from them feeding conduits to the respective reservoirs.
13. Some references to works of this type in some of these reservoirs are modern or correspond to natural erosion.
14. There is some data concerning an important repair work carried out in the eighteenth century, when the Conde de Campomanes refurbished the work with the purpose of using the water of the reservoir in a paper factory constructed some kilometres downstream from the dam. The structure which is preser ved today may correspond in part to this era, as at the time the large dam of El Gasco close to Madrid was constructed with a cell structure which to a certain degree is similar to that of Cornalvo (Martin et al 2000).

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