The great importance that water has played in all cultures, especially in those countries with unfavourable climates, is undeniable.

The easternmost area of the Iberian Peninsula and within it large areas of the Comunidad Valenciana may be classified as sub-arid. These particular climatic conditions produce irregular rainfall which has greatly conditioned the form of the rivers which drain the land.

The majority of the most southerly drainage basins receive annual precipitation of less than 400 mm and extensive areas with an average less than 300 mm. Additionally, if we bear in mind that this rainfall is usually concentrated in short time periods, the result is that floods occur with some frequency, especially in autumn.

These circumstances, along with the fact that population was principally found in river and coastal areas during certain periods, led to attempts from early times to control the irregular river flows to guarantee the supply of water to populations as well as the supply of irrigation water during the long periods of drought.

Cultures with a great tradition of water management such as the Arabs and the Romans obviously left a profound legacy. However, the continuity and intensity of the use of this infrastructure along with the destructive power of flooding has generated a regular succession of breakages, modifications, repairs and reconstructions, which often make impossible the task of recognizing the original constructions.

Much is the case with numerous diversion weirs, many of which are still in use and located on the final stretches of rivers such as the Turia, the Júcar or the Mijares and which for the aforementioned reasons will not be dealt with in this article. The article will focus the question on a group of dams; Tibi, Elche and Relleu —constructed between the 16 and 17 centuries in the province of Alicante and which constitute some of the most emblematic examples of ancient dams (excepting those of the Romans) not only within the Comunidad Valenciana but all Spain.

**FORMS OF THE DAMS**

These three dams, to which we may add that of Almansa (as much for its similarity of layout as being contemporaneous with that of Tibi) display many common aspects, while together signifying a milestone in the history of hydraulic engineering.

The most important common characteristics are: their curved layout, the system of galleries for the clearing of mud, the fabric used (based on masonry covered with dressed ashlars) and the fact of being emplaced on rivers of low average flow, heavy flooding and with wide areas of their watercourses made up of erodable detritus.

Nevertheless, the form and construction of each of these dams present some differences which should be pointed out.
Tibi dam

Work began on the Tibi dam in 1580 and merely one year later it suffered its first interruption due to economic difficulties which lasted nearly 10 years, a period which additionally served to modify the geometric characteristics following a bitter debate between the various experts who studied the construction. Although agreement was reached in 1588, the work recommenced in 1590 under the direction of Cristóbal Antonelli, one of the engineers of King Felipe II. The works reached their culmination around the middle of 1594 at a height of 196 palms when the town requested authorization from the King to conclude the works due to the lack of necessary resources required to reach the projected height (Alberola 1994).

The dam functioned normally until the great breakage of 1697 and there is only one report of a break in April 1601 (Bendicho 1640), which, it seems, was due to the incorrect handling of the outlet sluice gate.

Many authors have dealt with the causes of this breach (Maltés and López 1752; Cavanilles 1795; Viravens 1876; Camarero, Beviá and Beviá 1989; Alberola 1994) and in the documentation supplied it seems that various circumstances came together. In the year 1688 the silting-up of the reservoir was so great that only 22 palms remained usable (less than 5 metres). Consequently, the decision was made to open a breach «through the cavity wall where the water governor was, being the thinnest part» (ACA, Consejo de Aragón Leg. 863–2/4) so that the water would drag away part of the deposited sediment. The breach was closed with flagstones that were incapable of resisting the floods produced in 1697, which, combined with the weakening of the wall and the deterioration of the lime mortar caused by the circulation of water through it produced an important breakage and the emptying of the reservoir.

The dam remained unrepaird until the year 1736, when the works began which would finally prove definitive. Notwithstanding, in this extended period of time various reconstruction proposals were undertaken: Juan Blas Aparicio in 1698, Próspero de Verboom in 1721, José Terol, Vicente Mingot, Nicolás Puerto, Francisco Asensi and Juan Bautista Borja in 1733 and Pedro Moreau in 1733. In all of them, the breakage that the dam had suffered was represented along with proposals for its repair, all of which allows us to see the form of what has been preserved to the present-day as the most important changes have only affected the drainage systems and not the principal structure (Camarero et al. 1989).

The initial construction, interrupted at only a few metres height, possessed a rectilinear upstream face and a curved downstream face. This idea was rejected by all who made proposals for its recommencement, imposing instead a curved layout with an average radius of 90 metres. The upstream face has a gentle slope of 0.75/10, whilst the downstream slope shows six steps distributed in the following manner: a slope of height 18.6 m from the base, a first step of 1.0 m width and 5.25 m height, the second of 1.0 m by 4.5

Figure 1a
Tibi dam according to Cavanilles. Figure 1b. Tibi dam in 2002 year
m, a third of 0.8 m by 3.3 m, the fourth of 0.6 m by 2.5 m, the fifth of 0.5 m by 2.6 m and the sixth of 0.4 m by 2.8 m to finish off with a bevel of 1.3 m height.

The total height is 42.7 m, the width being 33.7 m at the base and 20 m at the crest.

With respect to the drainage mechanisms, there is a surface weir with two openings situated on the extreme right of the crest, a water intake through an embedded well in the dam placed one metre from the upstream face with 52 pairs of slits and a base sluice gallery with dimensions of 1.8 m width by 2.8 m height at the intake widening rapidly in three metres to $3 \times 3.3$ m and progressively increasing its size until it reaches 4.0 m. width and 5.85 m. height at the outlet.

The theoretical capacity of the reservoir is 3.7 Hm$^3$ and, although at the beginning of the 20th century an attempt was made to increase it, the scarcity of provision from the river Montnegre caused the idea to be abandoned. What was undertaken was the substitution of the clearing gallery for another excavated into the rock of the left edge, provided with two sliding panels. These works were begun in 1934 and concluded in 1943. Some years later, in 1945, a campaign of injections into the body of the dam was undertaken to reduce the filtration that had been detected.

**Elche dam**

The first project dates from 1589, the year in which the council of the town of Elche, faced with the reduction of available irrigation water from the river Vinalopó (probably due to the intensification of the use of upstream springs) formed a committee of experts to study the watercourse and undertake the formation of a proposal for a reservoir. This was made by Joan del Temple and Pere Izquierdo, who had participated in the projects of Almansa and Tibi respectively, along with the local masters Domingo Chavarría and Miguel Sánchez. Despite having obtained the necessary authorization from the ecclesiastical and civil authorities in 1590, the commencement of the works was delayed by the elevated cost of the Tibi dam, the rupture of 1601, and the decrease in the area of cultivated land as a result of the expulsion of the Moriscos (Gozámez 1977).

The emplacement of the dam was proposed on the narrowing of the river at the point of a hill named...
Castellar de Morera where rock outcropped throughout the enclosure. The principal stages of construction correspond to the periods 1632–1640 and 1643–1655, although the reservoir was not filled until the year 1672. (Irles, Jaén and Irles 2002).

The operation of the reservoir had numerous problems principally derived from two factors: the silting already mentioned in 1653 and the salination of the waters. To this we must add the important floods which sporadically occur in the river Vinalopó, contributing to the increase in sediment loads and frequently provoking faults in the gate of the drainage gallery.

All this led to the drawing-up in 1670 and 1732 projects for the construction of a diversion canal so that river waters could avoid the reservoir although the diversion was not undertaken until the 20th-century.

The silting and floods resulted in the filling of the reservoir with mud, which around 1751, rendered it unusable. Various remedial projects followed: that of 1762 with the change in the system of the closure of the base outlet or that of 1793 to reconstruct the sluice gate and vertical sliding door. In the same year Cavanilles visited the lake, finding it with the sluice door open, empty and silted-up. (Cavanilles 1795).

Throughout the 19th-century the periods of disuse under repairs alternated with periods of precarious operation until the Elche council opted for the transfer of the lake to the owners of Acequias Mayor y Marchena who refurbished the dam in the same year, without modifying the previous structure since the description of Cavanilles matches very well with the appearance that the dam presents today.

In accordance with the proposals of the civil engineer Prospero Lafarga (Lafarga 1910) between 1906 and 1910 a diversion of the river Vinalopó was undertaken before its entrance to the reservoir. Starting from the mill weir of Pavía a canal was constructed with a total length of approximately 4 km, of which 1.9 km were tunnelled and was in operation until the ‘40s when floods put the intake out of use.

New projects were subsequently drawn up to install a new base drain and to refurbish the intake of the diversion canal. However, only the latter work was carried out. The reservoir, little by little, lost interest for the irrigators as a consequence of the employment of other waters originating from the Tagus-Segura transfer, with the consequent abandonment of the exploitation, resulting in the spontaneous rupture of the base sluice drain due to its poor condition. Consequently, the reservoir proceeded to empty, carrying with it an estimated volume of 100,000 m³ of mud (Zaragoza 2002).

At the present time it seems that various refurbishment projects are undertaken as much on the reservoir itself as some of its accessory works which, in any case, must be compatible with the declaration in 1999 of the Generalitat Valenciana of the dam of Elche as an Asset of Cultural Interest (Irles, Jaén and Irles 2002).

With reference to the dimensions of the dam, it presents some peculiarities of great interest. It consists of two clearly differentiated parts. The main body, formed in layout by two curved sections and another smaller body situated alongside the right edge which, it seems, functioned at some time as a weir with a fixed lip, although at some later time it was heightened to the crest level of the principal dam.

The main body of the dam is formed by an arch with a 63 m. radius with a height above the watercourse of 23.2 m, width at base of 12 m and 9 m on the crest the inclinations being 0.049 and 0.092 upstream and downstream respectively. Some authors (Fernández Ordoñez 1984) consider it to be the first arch buttress dam in the world since its stability is precarious unless one considers the effect of the arch.

On the left edge the arch rests its lower section on the rock of the bank whilst the upper metres are closed with a straight wall positioned upstream.
according to the radial alignment. The other side of the arch rests on a rocky promontory existing in the center of the enclosure on which a buttress has been placed to improve the rim.

In addition, there is another arch of much reduced dimensions which encloses from a buttress to the bank of the right edge.

Around 100 m from the main body on the right edge there is a small hill enclosed by an arch wall 11 m in height and 7 m width at the crest, although it seems that the water level was 1 m lower than that of the principal dam when it functioned as a Weir.

The base drain constitutes a Gallery of 2,2 m × 2,7 m with half point vault, in which there were two gates, one near to the upstream face and composed of a rectangular sluice gate secured with horizontal beams sunk into lateral holes in the ashlar courses. The other was a vertical sluice gate operated from the sluice chamber situated above the base gallery and secured with horizontal beams and a large vertical log.

**Figure 5**
Elche dam. Interior of the operations chamber

The water intake consists of a well of 1 m in diameter, embedded into the body of the dam, with slits in alternate courses and height coincident with that of the ashlar and a width of 10 cm. This structure is not the original but corresponds to an important repair work carried out in 1764.

The theoretical capacity of the reservoir is 4 Hm³ though by the mid-20th-century the thickness of the silt deposits reached around 18m resulting in an estimated capacity of around one tenth of the theoretical capacity.

**Relleu dam**

This work is far less studied the previous two and the author of the project and date of construction are unknown. It is known that in 1653 the town of Joiosa managed and obtained a privilege of King Felipe IV, authorizing the construction of a reservoir on the river Amadorio. However, various authors do not agree on the year in which it was constructed offering various dates: 1628,1629 and even the 18th-century without supplying any reference with respect to the origin of the information (López Gómez 1987). Sendra (1964) gathers together an application of 1777 made by the population of Relleu to interrupt the heightening works on the dam, which could be one of the causes of the confusion about dates.

The work is emplaced on the river Amadorio on an impressive stretch immediately after the confluence with the creek of Marules. It is a dam of curved layout with a radius of around 60 m, vertical faces and thickness of 10 m. Initially, it had an approximate height of 28 m and was later heightened in 1879 to 31.85 m with a wall of four metres thickness.

The volume of the reservoir, after the heightening, was 600.000 m³ and although, now in the 20th-century, new enlargement plans were drawn up for the reservoir none of them was executed and, in 1961, with the entrance in operation of the reservoir of Amadorio of 8 Hm³ capacity situated a few kilometres downstream, the reservoir of Relleu ceased to be useful apart from the purpose of sediment retention and fell out of use.

**Figure 6**
Relleu dam. View from the right edge.
with slits of 0.25 m × 0.25 m, arranged regularly in the face to a height of approximately 9 m from the base. This is due to the fact that the enclosure is very narrow at the base of the reservoir and, until the water reaches to said water level, it doesn’t begin to open out until reaching the almost 40 m width of the crest.

The well is connected to the clearing gallery, which consists of a tunnel of some 2 m width, with an opening in the upstream face of 1.0 m × 2.0 m closed with a wooden sluice gate. Similarly, it possesses a operations chamber connected to the sluice gate by means of a well to which access is gained by means of a sloping gallery whose entrance hole in situated in the downstream face very close to the left bank and to which access is gained through some steps cut into the rock of the said bank.

**CONSTRUCTION ASPECTS**

The masonry of the three dams is very similar, the main core is composed of masonry bedded with lime mortar and rendered on both sides with a quality face of calcareous ashlar. Nonetheless, some small differences exist which, in many cases, correspond to the many repair works suffered.

The large quantity of existing documentation on the dam of Tibi allows us to know of some construction aspects which, doubtless, may be applied on general lines to other works. In the response of the experts to the memoir of 27 points of conflict over the work of Tibi, dated 7 Dec. 1587, it is recommended that «... In the front as in the lower part to carry on with segmental arches and that in the body of the work that the official, or officials should undertake the construction of masonry arches using appropriate seater stones on the rims» similarly, it was recommended to render with bitumen the joints in the faces in contact with water, from the center outwards «as is usually done in cisterns».

In the study which Próspero de Verboom conducted in July 1721, for the repair of the dam, it was recommended to use ashlar blocks of a greater size than was the custom in the locality as well as joining them with iron clamps set in lead in the most delicate areas. An interesting suggestion is made that it would be useful to bring puzolana from the kingdom of Napoli for use on the first face of the work in order to give it greater solidity as well as giving a more rapid entrance for water into the lake.
In the general chapters, the buyer was obliged to remove all areas that appeared to be in poor state, as well as to give special attention to the connections between old works and new works. To achieve this, it was necessary to unite the new courses with the old. Additionally, in the areas where forces were greater, it was necessary to unite them using iron clamps conveniently set in lead. In cases where it was necessary to set in the rock, they had to excavate the shape of the block to guarantee its perfect collocation. Similarly, in the masonry it was necessary to seat the stones properly with the blow of a hammer and overseat with a tamper so as not to produce the later seats.

Finally, among other conditions referring to the water intake and the drainage gallery, it was necessary to clean vegetation and roots from the crest, lifting all the courses that were necessary until
arriving at the clean area later replacing the blocks so that the work remains level.

The quality of the materials used in the three dams must have been very similar, as all have tolerated the passage of numerous floods over the crest without appreciable damage. The limestones used in Tibi as well as the myocene calcrites extracted from the quarries still visible on the left edge of the dam of Elche over the nummulitic limestones used in Relleu are of sufficient quality to have maintained the aspect of these works and despite the passage of years, often in neglect and abandonment.

Unfortunately it is necessary to point out another characteristic common to these three works: the poor signposting and bad condition of their respective access roads, which, perhaps, shows an apparent lack of interest for hydraulic heritage despite some of the dams being declared Asset of Cultural Interest by the corresponding administration.

**REFERENCE LIST**


Sendra Barber, Alejandro 1964, *El pantano de Relleu*. Boletín de la Comunidad de Regantes de Villajoyosa. 30 de noviembre.
