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REVIEW ARTICLE

Mining Dams as Industrial and Environmental Heritage: The Mining Dams of Huelva (Spain)

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Abstract
UNESCO defines heritage is the legacy we inherit from the past, which we live with today, and which we will pass on to future generations. Our cultural and natural heritage is an irreplaceable source of life and inspiration. The province of Huelva, in Andalusia, Spain, has a rich mining history that has left a significant legacy in its landscape and culture. Industrial Heritage encompasses both movable and immovable assets created throughout history by human extraction and production activities. The assets are integrated into a specific environment that must also be protected, as industry arises from society's use of the natural environment. Among the most outstanding elements of this industrial heritage are mining Dams, fundamental structures for water management and environmental preservation in extraction areas. This work documents the history, construction methodology and state of conservation of the main mining Dams in Huelva, assesses their heritage value, analyses their environmental impact and explores their educational and tourism potential. It also identifies the challenges and proposes conservation strategies to ensure the preservation of these unique constructions.

Keywords Industrial Heritage · Mining Dams · Huelva Mining Heritage · Cultural Legacy · Industrial tourism · Preservation Strategies

Introduction

Mining has been a fundamental economic activity in the province of Huelva since pre-Roman times. Reservoirs have played a crucial role in twentieth century mining, due to several key factors that have influenced the efficiency, sustainability and safety of mining operations, as they have been considered a necessity for the different phases of exploitation, they have been built to manage water and protect the environment, being evidence of the ingenuity and technical capacity developed over the centuries.

Water, so necessary in all the processes of the mine's life, has a series of connotations that should be highlighted:

- As a problem to be solved by dewatering or eliminating it during exploitation.
- As a need to be used for its exploitation, inside or outside the mine.
- As an environmental resource to be protected, demonstrating that mining today is committed to the environment.

It is therefore a critical resource for mining projects; its management and protection are essential for any mine. Although mining does not consume as much water as many industrial and agricultural activities, it needs to ensure a constant and adequate supply as a necessity (INPUT), while at other times we find that we have to drain large amounts of unwanted water at the project level as a handicap (OUTPUT). Handicap management therefore requires the right approach, the right methodology and the right integration into

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the management environment. For this reason, all the mining companies that have exploited the deposits in the province of Huelva have had the need to build reservoirs and mining Dams for the INPUT–OUTPUT binomial of water, thus becoming important industrial elements in the mining projects that, over time, have become part of the mining industrial heritage.

This heritage has been created by the processes of exploitation and transformation of industrial sectors, especially since the Industrial Revolution. Many industrial buildings and installations, once obsolete and dismantled with a blowtorch, are now considered by some groups to be'modern cathedrals'. Also those industrial parts such as machines, derricks, jetties, etc. stand out as interesting works of art created by society, shaped by engineers, technicians and workers. When these elements disappear, they begin to be valued as heritage, which is why it is no coincidence that in the 1950 s the so-called'industrial archaeology'emerged in the United Kingdom at the hands of local authorities, encouraging spontaneous public participation in their preservation and recovery (Douet 1997).

The term"cultural"is understood as a synonym for"historical"and includes all those assets, signs or manifestations that bring us closer to the knowledge of past civilisations. Until 2007, the concept of industrial heritage did not appear as such in legislation, as it was considered to be included in ethnographic and scientific-technical heritage, both of which are recognised by the LPH (Romero Macías 2011). It was not until the Order published on 20 November 2007 under the Andalusian Historical Heritage Law that the concept of industrial heritage took on a certain importance and, according to its Article 65, is defined as"the set of assets related to the productive, technological, manufacturing and engineering activity of the Autonomous Community of Andalusia, insofar as they are exponents of the social, technical and economic history of this community". The Andalusian legislation was a pioneer in recognizing industrial heritage in the field of cultural heritage and, therefore, it is considered an innovative process and a reference to the different laws on heritage in other Spanish communities. In addition, a new, broader concept has been introduced, that of Historic Site, which includes'places linked to events or memories of the past, to traditions, cultural or natural creations and human works, which have a relevant historical, ethnological, archaeological, palaeontological or industrial value'.

Mining heritage refers to the totality of tangible and intangible assets and elements generated by mining activity throughout history. These include the infrastructure and tools used in the extraction and processing of minerals, landscapes, deposits, mining towns, technical knowledge, cultural and social traditions, and the environmental changes that have resulted from this activity. The most striking example is the Cuenca Minera de Riotinto, considered to be the oldest mining site in the world, where traces of metal extraction date back to the Chalcolithic period (Pérez 1996). It is true that of these more than 5000 years, two periods stand out: the Roman period, between the second century BC and the fifth century AD (Pérez 1998), and the period when the mines were exploited by a consortium of foreign capital, mainly British, Rio Tinto Company Limited, between 1873 and 1954 (Harvey 1981).

It is therefore necessary to consider the hydraulic works (hydraulic heritage) as part of this heritage, although until now only fountains, tidal mills and river mills have been taken into account (González Tascón and Bestué Cardiel 2006), but Dams and weirs have never been included as such heritage elements, and it is for this reason that this work aims to give them the importance they have had within the extractive activity in the province (González Tascón and Bestué Cardiel 2006). 'The El Bierzo Charter for the Conservation of Industrial Mining Heritage' is an exercise in reflection on the cultural values of the assets linked to industrial mining and presents a methodological proposal for their preservation and public enjoyment (Instituto del Patrimonio Cultural de España (IPCE) 2009).

Historical and Mining Context of Huelva

It is difficult to date the beginning of mining activity as such; its beginnings date back to the most distant times of Palaeolithic cultures (Gonzalo y Tarín 1886) and its first applications, linked to primitive architectural structures (use of stone and mortar) and the manufacture of tools and implements.

The mineral wealth of the province of Huelva has shown that these mining areas, located in the Iberian Pyritic Belt, have been continuously exploited since ancient times. The oldest documented workings are in the Cuchillares (Campofrío) mine, dating from the Chalcolithic or Copper Age (Blanco and Rothenberg 1981). At that time, the mining activity focused on the exploitation of copper carbonates (malachite and azurite). By the Early and Middle Bronze Age, these deposits had been exhausted, which led to the exploitation of secondary enrichment zones where silver-rich minerals were found. The site where the oldest silver metallurgy in Western Europe has been documented, La Parrita (Nerva), dates back to 2900 BC (Pérez 1996).

In several copper deposits in the pyritic belt of Huelva and Seville, there are numerous mines from the Roman period, in some of which some of the mining techniques introduced by the Romans have been found, especially those related to drainage (Fig. 1), which was a problem in terms of deepening the mines.

The mines of Riotinto continued to be exploited in the Middle Ages and in modern times, although they were less important than those of the Roman period and the second half of the nineteenth century. It was not until the nineteenth century that the growing need for metals, especially copper for the minting of coins and naval artillery, encouraged the search for and reuse of old mines, especially those of Roman

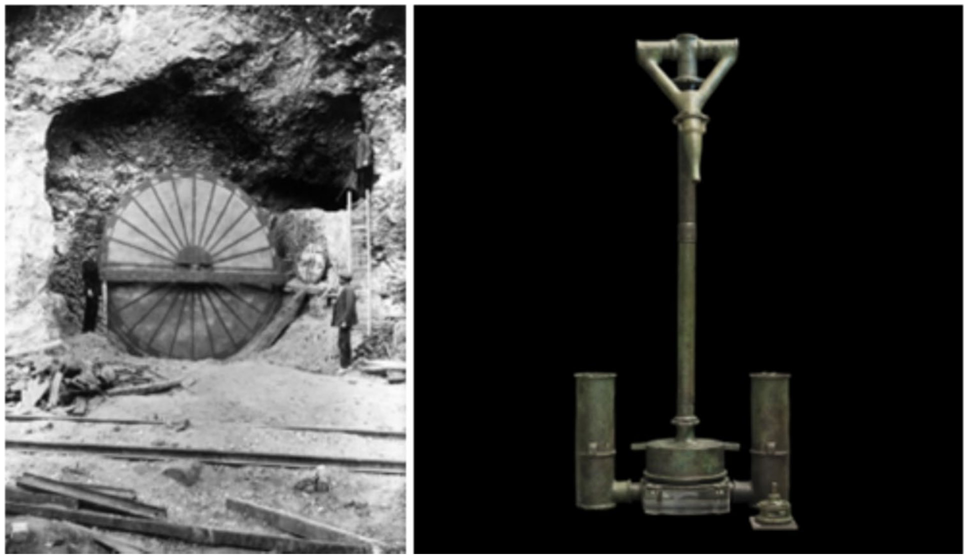


Fig. 1 Roman drainage elements. The figure on the left is a Roman waterwheel found in Riotinto (F.R.T. Archive), and the figure on the right is a Ctesibius pump found in Sotiel (National Archaeological Museum)

origin. For 148 years, Riotinto was managed directly by the Royal Treasury (Pinedo 1963) or, at certain times, leased to private individuals.

In the middle of the nineteenth century, all the mining concessions began to be exploited intensively. The demand for sulphur for the nascent chemical industry, after Sicilian supplies were exhausted, and the urgent need for copper attracted foreign capital. In addition, the First Spanish Republic, in need of liquidity, sold the Riotinto mines in 1873 to a foreign consortium, the Rio Tinto Company Limited, for ninety million pesetas, the equivalent of 550,000 € (Flores 1982).

In the twentieth century, mining in Huelva continued to be a funDamental economic activity, although it faced several challenges, fluctuations in metal prices and changes in world demand. In the last decades of this century, the mining industry was further modernized, although some mines closed due to diminishing reserves and global competition.

Today mining in Huelva has declined compared to its boom in the nineteenth and twentieth centuries, but it is still important and new deposits are being discovered. The region continues to produce minerals, albeit with a more sustainable approach and a greater emphasis on environmental protection.

Economic and Social Importance

Mining has been an economic pillar for the province of Huelva, driving the development of infrastructure and urbanisation. Mining has transformed the landscape and society, creating jobs and attracting workers from different regions. It has been one of the main economic engines of Huelva, generating numerous direct and indirect jobs over the centuries. From extraction to processing and logistics, thousands of families have depended on this industry. Mining has driven the development of key infrastructure in the region, including roads, railways, Dams and ports. This infrastructure has not only facilitated the transport of minerals, but has also benefited other economic sectors and the population in general.

The area has attracted significant foreign investment, particularly during the Industrial Revolution when British and French companies led the way in the extraction of minerals such as copper and pyrite. This investment contributed to economic growth and the modernisation of mining techniques. Huelva's mineral wealth has allowed it to diversify its economy. In addition to mineral extraction, related industries such as metallurgy and chemical production have developed, adding value to local resources. Mining has been an important source of income for the regional economy, contributing significantly to Huelva's Gross Domestic Product (GDP). Mineral exports have generated foreign currency and improved the province's balance of trade.

Socially, mining has been a key factor in the urban development of the province of Huelva. Mining towns and villages such as Riotinto and Tharsis have grown up around mining operations, attracting workers from different regions and cultures, which has enriched the social and cultural fabric of the province (Ruiz 1998; Pérez et al. 1999). Mining investments have contributed to improving the quality of life of the inhabitants of the mining areas of Huelva. The creation of well-paid jobs and improvements in infrastructure and public services such as education and health have had a positive impact on the local population.

Culturally, it has left a strong mark on Huelva, with festivals, traditions and industrial heritage, including pithead Dams and other architectural elements, all testifying to the mining past and forming part of the region's cultural heritage. The need for skilled labour in the mining industry has driven the education and training of workers, and educational institutions and vocational training programmes have been set up to meet this demand, raising the level of education and technical skills of the population.

Description of the Mining Dams Studied

Since ancient times, water availability has been a crucial factor in the establishment and development of human settlements, directly influencing the occupation of territory and the distribution of the population. Maintaining a balance between water needs and availability has depended on numerous variables that can be grouped into two main categories: physical and social (Bueno Hernández 2005). Physical variables refer to the natural environment in which human activities take place, while social variables include historical, political, military, social and economic aspects.

The search for this balance has led to the adoption of different solutions adapted to the specific circumstances of each time and place. Among these solutions, diversion Dams and weirs have played a prominent role throughout history and in all civilisations, proving to be essential for efficient water management.

Many of the country's Dams and weirs were built to enable the operation of industrial complexes, supplying them with water or the hydraulic energy needed for their production processes. Thus we have foundries, steelworks, hydroelectric plants, mining complexes, etc., all of which operate thanks to the water captured and released by the Dams and/or weirs.

It is important to point out that Spain has been a pioneer in the construction of Dams, especially in the twentieth century, with a wide range of construction models that have led to the development of a first-class technique at the forefront of hydraulic engineering at many points in its history.

The number of Dams in Spain has grown exponentially, especially during the twentieth century and up to the present day. This has led official bodies (currently the Ministry of Ecological Transition and Demographic Challenge) to develop tools for knowledge, protection and conservation of this heritage. In the 70 s of the twentieth century, the first inventory of Dams in Spain was made, which has been updated until today, preceded by a first attempt in 1946 (Pérez Marrero 2017). An example of this trend is the percentage of Dams catalogued today in relation to their date of construction. We can see that Dams built between the first century BC and 1900 represent 3.58% of the total, those built between 1900 and 1910 represent 0.91% and those built between 1910 and 1920 only 3.38%.

Therefore, Dams built before 1920 account for only 7.87% of the total number of Dams in the national catalogue of public and private Dams. This catalogue, however, focuses mainly on the most modern and operational Dams.

Today, 144 Dams and reservoirs have been inventoried in Huelva, with different construction methods, uses and state of maintenance (connotations as to the type of use), as shown in the following Figs. 2 and 3.

For this work, we have resorted to the detailed study of two Dams in the province, which serve as excellent examples of the wide catalogue of hydraulic structures associated with mining.

Specifically, the Dams analysed are those of Alisal-San Miguel (Fig. 4), in the municipality of Almonaster la Real, and Calabazar (Fig. 5), in the municipality of Calañas, both of which are associated with active mining operations and which, in turn, require stored water. It is therefore necessary to assess the state of preservation of the structures and to take the necessary corrective measures to guarantee their structural stability.

The Calabazar was built at the beginning of the twentieth century to meet the water needs of the Sotiel Coronada mine.

The need for it arose from a change in the method of extracting copper. The cheapest way for the companies was to process the minerals and extract the copper using the so-called"dry method"or artificial cementation, which consisted of calcining the mineral in the open air in the

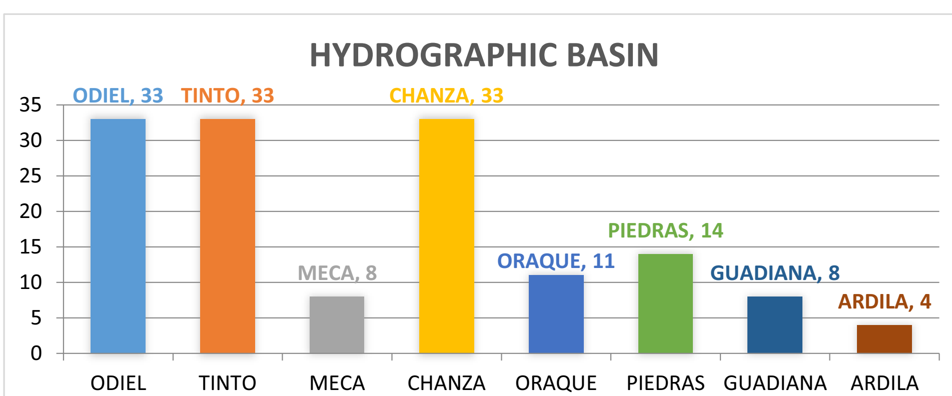


Fig. 2 Distribution of Dams by river basin

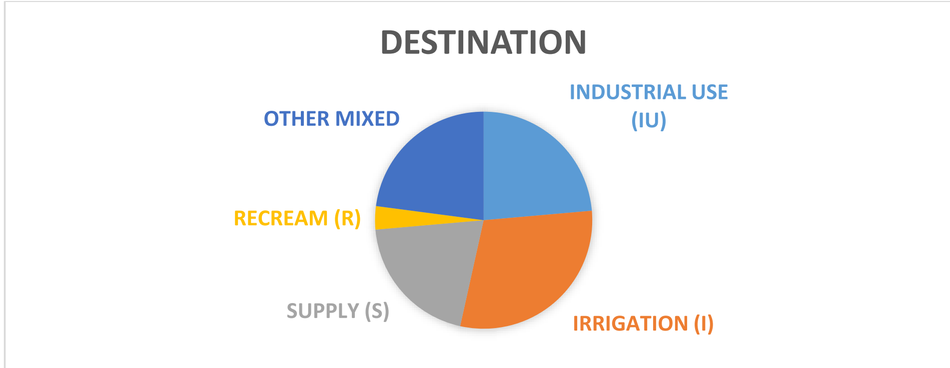


Fig. 3 Dam distribution by type of use

Fig. 4 View of the Alisal Dam

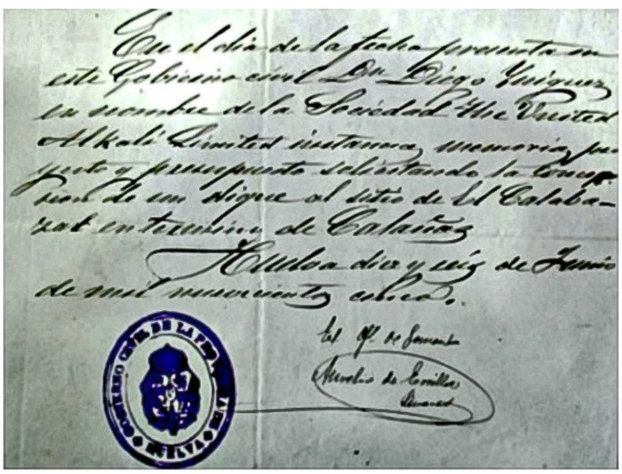
so-called"teleras". This method was the most economical for the companies, but it created a serious environmental problem: it produced a large amount of sulphurous gases, which seriously Damaged the vegetation and therefore the agricultural and livestock farms in the area. This led to serious confrontations between the people affected and the mining companies.

With the prohibition of the"teleras", it was necessary to look for another way of extracting the mineral and the so-called"wet method"was chosen, in which the mineral was collected in specific areas called"terreros". This method allowed the leaching of copper with acidic water, facilitating its extraction (Ortíz Mateo 2003). and irrigated with large quantities of water; these leaching waters flowed into"canaleos", or systems of zigzag canals with a minimum gradient, into which iron scrap was introduced where, through chemical processes of ion exchange, the fine copper was deposited in the form of a shell. This process required large amounts of water, so most mines had to build reservoirs with plenty of water to supply the processes and consumption. Initially, Sotiel used the water of the Odiel River, but it became increasingly polluted by the mine waste dumped at its headwaters, so its water was considered unsuitable for its canals. In 1905, therefore, the Alkali Company decided to build a reservoir to meet its needs (Fig. 6).

Structurally, both are gravity structures with a triangular profile, following the design models of Lévy, contemporary with the beginning of the twentieth century (Pérez Marrero 2017). They have a similar height, around 24 m from the foundation to the apex, a width of 2.5 m at the apex, and a masonry body. As significant differences, and which conditioned the diagnostic tests, Calabazar has a rectilinear trace of 59 m and a crown parapet that limits the width of the passage. Alisal-San Miguel, on the other hand, has a pronounced curvature along its 111-m length, and the crown wall has been amputated.

The construction details and the methodology used are described below, thanks to the information obtained from

Fig. 5 View of the Calabazar Dam



En el día de la fecha presenta en este Gobierno civil Dn Diego Vázquez en nombre de la Sociedad The United Alkali Limited instancia, memoria, proyecto y presupuesto solicitando la concesión de un dique al sitio de El Calabazar en término de Calañas.
Huelva diez y seis de Junio de mil novecientos cinco.

Fig. 6 Copy of the application for the construction of the Calabazar Dam

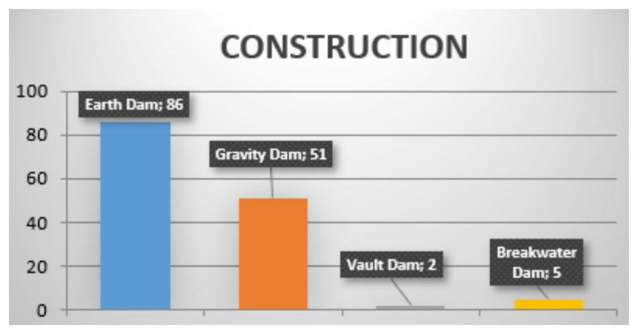


Fig. 7 Distribution of Dams according to construction type

the direct geotechnical tests carried out on the body of the Dam and the geological framework.

Study Methodology

The mining Dams of Huelva provide an excellent illustration of the considerable advances in hydraulic engineering that have occurred throughout history. The construction techniques employed varied considerably, encompassing the utilisation of local materials and the incorporation of technological innovations that were available at the time, with the objective of enhancing efficiency and safety (Fig. 7).

Publications and inventories on this type of structure are numerous and very complete. However, there is little technical information available beyond some details of the original projects or indirect quotations of the works.

We must remember that after the Dams were abandoned in the 50 s of the twentieth century, neither the owners nor the public administrations monitored or surveyed them. It was not until the beginning of the twenty-first century, when new companies started operating, that the need to enhance the value of these structures for the use of the stored water was taken up again.

The study of the structural and geotechnical stability of Dams involves geotechnical investigations, such as rotary boreholes (González Vallejo et al. 2002), both of the geological environment and of the body of the reservoir in the form of masonry cores, or geophysics (MASW 2D and electrical tomography). It is therefore a comprehensive study based on direct and indirect information on the construction of these unique elements.

As mentioned above, the absence of the original crest wall of the Alisal Dam (Fig. 8) allowed access with a crawler probe, providing the opportunity to drill into the structure and learn about the materials, mechanical resistance and possible pathologies. By extrapolating the knowledge of both construction techniques, it was possible to create a faithful model of the techniques used.

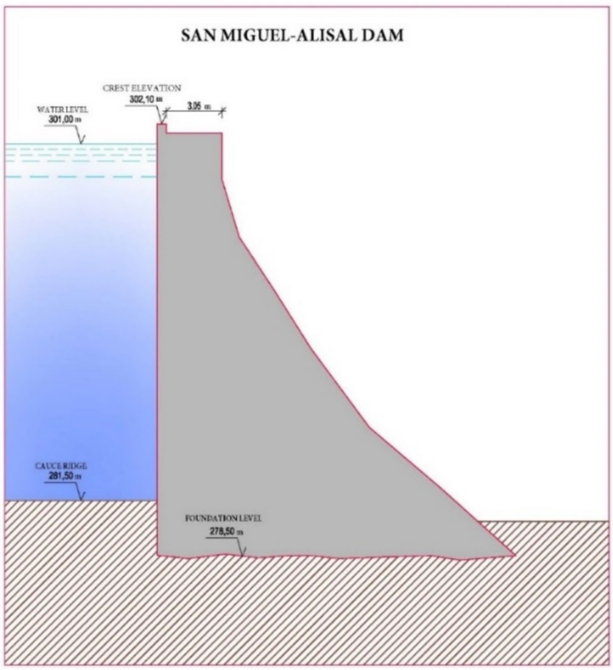


Fig. 8 Alisal-San Miguel Dam cross section

The construction of gravity Dams with masonry was a significant advance in hydraulic structures for the storage of rainwater. From the beginnings with earth Dams and breakwaters, derived from the nearby waste Dams, we moved on to large capacity reservoirs that reached significant heights for the time. In particular, the industrial Dams of the late 19 th and early twentieth centuries stand out for their artisanal use of lime mortar and original aggregates.

The strategic importance of the lime quarries and kilns in the province is well known. In particular, the town of Santa Ana la Real stood out for the production and quality of this product, funDamental in construction, with up to 14 kilns that were used to calcine the limestone extracted from the nearby frontiers to obtain quicklime. The process required high temperatures, which were obtained by burning large quantities of dry wood from the municipal forests. This industrial production made it possible to supply the mines in the region with this binding agent. Historically, the supply routes to the Dams have been recorded, using herds of animals, in our case up to 60 km to Cueva de la Mora and about 20 km to Sotiel Coronada.

The rotary drilling studies carried out in Alisal-San Miguel (Fig. 9) allowed us to describe the construction sequence in detail, confirming a Dam body of about 16 m and a foundation of 8 m. Specifically, the Dam is built with a mixture of local rock aggregates (quartzite, greywacke, shale, etc.) and the addition of the lime mortar mentioned

Fig. 9 Detail of drilling machine and core collection at the Alisal-San Miguel Dam

above, inside the"formwork caissons". The mortar was poured and watered in order to allow it to harden and grow.

To complement the information from the vertical cores, horizontal cores were taken from the downstream face. The criterion for their placement was to look for points where anomalies or irregularities previously identified by visual inspection appeared.

In Alisal-San Miguel, a first zone is described from the ridge to a depth of 16 m, where the factory shows a heterogeneous relationship between the herogenic and angular clasts and the mortar matrix. In general, it has porosity and voids, especially around the aggregates, which is normal in an artisanal practice of more than 100 years ago.

The average resistance of the cores to simple compression is 61.6 Kp/cm^2 and the tensile strength is 244 Kp/cm^2. Using the Rock Quality Designation (RQD) as a criterion for assessing rock quality (Ferrer and González Vallejo 1999), the structure reflects values between $<25\%$ and $>75\%$. Using the RQD index, we have a class from I (very poor) to IV (good) (Fig. 10).

Beneath this we find what we define as the Dam foundations, consisting of blocks of rock, mainly tuffite, quartzite-quartz sandstone and grey shale, approximately 8 m thick. These measurements would be consistent with the project data which defines a 24 m downstream limit profile. The average simple compressive strength of the cores is 157.4 Kp/cm2.

The borehole is completed by drilling to 35.4 m from the top to test the natural unit of support, which consists of the rocks of the volcanic-sedimentary complex (tuffs, epiclasites, quartzites and schists). The average simple compressive strength of the cores is 162.3 Kp/cm2. The RQD of the source rock is 25%−50% and $>75\%$. The RQD classification ranges from II (poor) to IV (good).

The hole was cased with 35 m of piezometric tubing for water control within the structure. The latest measurements show the presence of water 4 m from the crest.

In the Calabazar Dam, the rotary drilling had to be carried out at the base of the Dam, downstream, as it was impossible to place a drilling rig in the upper area. It was 6 m deep and allowed the description of the existing debris, part of the Dam's mortar wall and the bedrock (Fig. 11).

The first two can be considered as remobilised material from the slopes of the stream and anthropic remains of the auxiliary structures. Next, we have 1.5 m of the structure of clasts with lime mortar in different proportions. They are in a poor state of preservation, with cavities and washings. The simple compressive strength values of the cores were very heterogeneous, without criteria of depth or location (Fig. 12). Strengths ranged from 73.3 to 527.2 Kp/cm^2.

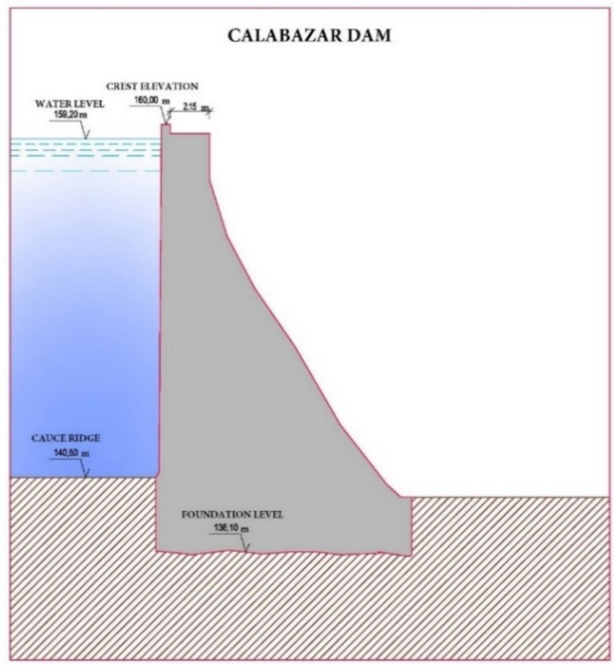


Fig. 11 Calabazar Dam cross section

Fig. 10 Alisal-San Miguel Dam borehole core box

Fig. 12 Detail of drilling machine and core collection at the Calabazar Dam

Finally, 3 m of very hard shale and quartzite were cut. The average simple compressive strength of the cores is 315 Kp/cm^2. The RQD of the embankment section is 0% and 25–50% for the rocky substrate. The classification according to the RQD index ranges from I (very poor) to II (poor) (Fig. 13).

The criteria for the placement of the cores in the structures were the locations where anomalies or irregularities had been previously identified by visual inspection. In the Dams of this period, it is common to find a vertical crack in the centre of the face, which completely crosses the structure (Fig. 14).

During the first visits, these were described as defects or pathologies that had developed over time, as they showed deterioration due to loss of material and continuous filtrations. It therefore seemed to us to be an interesting area to look for weaknesses in the structure.

The analysis of the information obtained in the field and the documentary information led us to the conclusion that this element is a joint derived from the construction method of the water Dams. This work was carried out from the abutments to the central area of the riverbed. In this way, the walls protected the rocky outcrops at the ends and allowed the water to flow through at all times.

It should be remembered that these were complex works due to the accessibility and nature of the materials. The possibility of torrential floods cannot be ruled out, which would have endangered the construction elements and the people working in the pits.

To sum up, the lack of interest, the absence of adequate studies and the scarcity of maintenance and rehabilitation measures can be attributed to two main factors. On the one

Fig. 13 Sounding witness box and detail of them, of the Calabazar Dam

Fig. 14 Location in the areas of anomalies visually detected in the walls of both Dams

hand, the social factor: Dams are located outside towns, often in places that are difficult to access and rarely visited, even by those who live nearby, which has led to their being forgotten. On the other hand, the functional factor: few of these old structures are still used as reservoirs. As they have lost their original function and there is no interest in preserving them for other purposes, abandonment and deterioration have become increasingly evident.

Results

From the study of two Dams representative of the industrial era at the beginning of the twentieth century, we found that after the prohibition of the use of incineration in Las Teleras and the change to the wet method of extracting copper shell, the mining companies resorted to the construction of Dams with a systematised procedure and with a high level of safety. XX, we found that after the prohibition of the use of incineration in Las Teleras and the change to the wet method for obtaining copper shell, the mining companies resorted to the construction of Dams with a systematised procedure and methodology.

These were masonry gravity Dams built with polygenic aggregates from the environment and lime mortar as a binder for the mixture. The walls were built directly into the rocky substrate or with the help of a foundation made of blocks taken from the clearings on the site. The sequence was ascending and growing from the edges of the Dam in order to consolidate the setting of the walls and to allow the flow of the ravine to pass through the central area.

As it was a highly manual construction, we found a similar factory made up of angular clasts of quartzite, greywacke, schist, etc., and a coarse, porous matrix with millimetre-sized cracks. The values obtained in the tests for resistance to uniaxial compression (UNE-22–950-90) are very variable. We found ranges close to 61 Kp/cm^2 for the Alisal-San Miguel Dam and between 73.7 and 527.2 Kp/cm^2 for the Calabazar Dam.

The difference in results is explained by the heterogeneity of the aggregate/cement ratio, which is clearly reflected in the cores. The highest values are assigned to the cores with the highest presence of clasts, while the lower fractures correspond to the mortar. We understand that the representative values are between 60 and 90 Kp/cm^2 (class R2 according to the ISMR classification). If we compare these results with the current regulatory framework, such as the Technical Building Code DB SE-F (Ministerio de Fomento 2019), we can see that the fractures are higher than those required (> 50.98 Kp/cm^2).

The results of the auxiliary diagnostic tests indicate that the choice of the location of the enclosures was based on criteria of storage capacity and proximity to the operations. Numerous geological anomalies were detected, such as faults, discontinuities or folds, which required on-site measures to ensure the efficiency of the structures.

The compressive strength values of the bedrock and foundation blocks are in the range of the massive rocks of the volcanic-sedimentary complex (around 160 Kp/cm^2 at

San Miguel-Alisal and over 300 Kp/cm^2 at Calabazar). As a result, the load-bearing capacity of the bedrock is sufficient to support the loads transmitted by the structures.

The explanation for the low percentages of RQD in the body of the Dam lies in the techniques and materials used. We have factories with different granulometries and equipment that did not allow adequate vibration and compaction of the matrix. This resulted in high porosity and the presence of coking in the mortar, which led to poor recovery in the cores.

The installation of a continuous piezometer in the body of the San Miguel-Alisal Dam provided excellent information on the permeability of the vaults. The continuous monitoring of the water level in the piezometer allows us to define a water level 4 m below the top of the Dam (project elevation + 298.18 m). This is undoubtedly the most worrying factor derived from the auscultation. The downstream boundary must be impermeable to contain the water, and uncontrolled inflows can cause severe structural Damage and jeopardise the overall stability of the structure.

It is important to note that, despite their age and lack of maintenance, they continue to fulfil their water storage function. They are therefore structures in good structural condition, with no apparent pathologies or anomalies that could indicate a risk of collapse or catastrophic failure.

We insist on the crucial importance of carrying out these auscultation and instrumentation works on clean water Dams, in order to know the state of preservation and to evaluate the stability and integral safety. They also allow us to improve our knowledge of the procedures, techniques and constructive uses of these hydraulic structures, which are so important in the province's historical industrial heritage.

Maintenance and Safety

The management and maintenance of mine Dams is essential to ensure both their structural durability and environmental protection. This requires the use of new technologies and continuous monitoring to prevent potential risks (Guo et al. (2024).

Prior to any intervention on an old structure, it is essential to carry out a detailed analysis. This analysis should include not only a review of the physical structure and hydraulic mechanisms, but also archaeological and historical aspects and their interaction with the environment. In addition, its impact on the geographical organisation of the area must be assessed, taking into account its current state and its evolution over time. This comprehensive approach allows us to assess the work in a respectful manner and to consider its reuse, especially if the structure is still in good condition, even if it can no longer fulfil its original function of water storage or if its current capacity is insufficient for conventional uses.

The safety and maintenance of mine reservoirs therefore requires a comprehensive strategy that includes regular inspections, preventive maintenance, proper water and waste management, contingency planning, technological innovation, regulatory compliance and environmental sustainability. These efforts not only ensure the stability and functionality of Dams, but also protect the natural environment and nearby communities, promoting a balance between development and conservation.

Heritage Interest

Cultural and Educational Importance

Mining reservoirs, which are structures designed to store water used in mining activities or to contain waste generated by these activities, can be considered part of the industrial heritage for several reasons. This recognition highlights not only their historical and technological importance, but also their cultural and social impact. These Dams should be considered not only as functional structures, but also as part of the industrial heritage of Huelva, representing constructive models that met the needs of the areas where they were located, mainly for supply needs and/or as part of the extractive industry process. Today, in many cases, these Dams or reservoirs can be transformed into recreational and nature interpretation areas (Jelen 2018).

Heritage Protection

Mining tourism is considered a form of cultural tourism (Valenzuela Rubio et al. 2008) that offers alternatives to traditional destinations by revitalising degraded areas and reusing obsolete facilities. This type of tourism is concentrated in rural areas with a large territory that transcends municipal boundaries and has a tradition that goes back to historical times. Unlike industrial heritage, which only covers the last two centuries, mining tourism offers a greater variety of typologies and resources, including archaeological, landscape, ethnological, industrial, documentary, artistic, monumental and historical aspects (Pérez and Romero 2008).

The decline and subsequent crisis of the mining industry favoured the plundering of heritage, as the various facilities and infrastructures, once they lost their functionality, became a source of alienation, and also led to a severe economic and social depression with high unemployment rates, which caused a large part of the working population to emigrate, favouring an ageing and low population density (Pérez and Delgado 2011). However, mining tourism has contributed to changing the image of these areas, transforming degraded landscapes into cultural landscapes that tell the history of the area, while serving as a resource for economic recovery. This process of valorisation of forgotten heritage seeks effective strategies to revitalise declining mining areas (Martínez and Pérez 1998; Pérez 1998), which in short is nothing more than giving value to their forgotten heritage, based on valid strategies that contribute to the recovery of depressed mining areas (Llurdés 1999).

Mining reservoirs have a remarkable tourist and educational potential. For example, places like Riotinto already attract visitors interested in industrial history, and the Dams can become key points for tourism and environmental education, also benefiting other mining areas where the Dams studied are located.

Tourism and Education

According to Morales and De las Casas (2003), the conservation of mining Dams as heritage elements requires a combination of conservation policies and the promotion of their historical and cultural value. It is essential to involve the community and local authorities in these efforts.

In the case of structures that are still functioning as Dams, it is crucial to approach any extension or rehabilitation with particular care. It is important to recognise that refusing to carry out these actions, when they could solve a functional need, could be detrimental to the work itself. The best guarantee of conservation is undoubtedly its usefulness.

For those Dams where it is not feasible or profitable to use them as reservoirs, there are various options for their use. One attractive option is to use them for recreational and leisure purposes, which are in high demand and compatible with respect for the original structure (Vargas Sánchez 2015). Reservoirs are ideal for this function because of the unique characteristics they bring to the landscape, such as greater humidity, vegetation and fauna. As examples of this type of use, the best known in the study area are Mina de Sao Domingos in Portugal, where canoeing competitions are held, as well as having a river beach, and Puerto de Zumajo in the municipality of El Campillo in Huelva, which is also used for summer recreation and for organizing kayaking competitions and other water sports. As shown in Fig. 15, the Port of Zumajo is a popular location for the practice of water sports (Phot. Carlos Rojas), while Fig. 16 shows the sports facilities at the São Domingos reservoir mine in Portugal (Phot. Juana Martín). In short, the aim is to provide them with a use that facilitates knowledge and access to this part of our hydraulic heritage, thus justifying their conservation in a natural way.

Conclusions

The heritage of Spain's historic hydraulic infrastructures of this type is therefore very important from an archaeological, historical and cultural point of view. They are not only witnesses, but also part of our history. Without them, it is difficult to imagine what would have become of Emerita Augusta, or of the numerous Roman villas with their irrigation systems, of the countless mills, aqueducts and irrigation ditches that have dotted our geography, of the Extremadura countryside, or of many other towns or activities where Dams and weirs have been their support, sometimes basic, sometimes complementary, but undoubtedly necessary.

Fig. 15 Practice of water sports in the Port of Zumajo (Huelva). (Fot. Carlos Rojas)

Fig. 16 Sports facilities at the Sao Domingos reservoir mine, Portugal. (Fot. Juana Martín)

The current situation of Spain's historic Dams is not the most desirable from a heritage point of view. They are generally in a state of disrepair, unknown to the public, historians, archaeologists and engineers. Paradoxically, some of these Dams and weirs, which have given rise to various activities and urban centres, are located just a few metres from other well-known heritage elements and, despite their proximity, there are not even any signs to indicate their existence and their historical and cultural importance, even though these other elements would not have been built without them. It is therefore necessary to make an effort to promote this important and fascinating heritage.

However, we should not set a certain age for them to be considered historic. Contemporary Dams are also part of history, many of them were built in the twentieth century and deserve to be recognised for their social and economic importance. Some of these Dams have received international recognition and appear in manuals not only of engineering, but also of art and cultural heritage, on the same level as buildings and industrial heritage. It is paradoxical that in Spain these works are less known and recognised than in many other countries.

The mining Dams of Huelva are valuable testimonies of industrial history and engineering. Their heritage value lies not only in their original function, but also in their capacity to narrate the technological evolution and environmental awareness in mining. The preservation and valorization of these structures are essential to keep alive the memory of Huelva's rich mining tradition.

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Declarations

Competing Interests The authors declare no competing interests.

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