

DAMAGE assessment of cultural stone heritage in reservoir environments

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Abstract – DAMAGE project – recently funded – will address the analysis of the deterioration of stone constructions of cultural heritage located in fresh water reservoir environments, which, due to periods of drought, emerge totally or partially. In the selected case studies the construction materials and the type of deterioration will be characterized by in situ analysis with portable and non-destructive techniques (TND) and in the laboratory, together with simulation tests or accelerated artificial aging. Likewise, the technological development of some techniques will be carried out for its adaptation to be measured in underwater conditions, the development of a predictive mathematical model and the elaboration of a protocol in which the scientific-technical methodology to be followed is indicated when the study of the conservation status, deterioration and durability of stone patrimony submitted to partial and cyclic immersion and outcrop stages is approached.

I. INTRODUCTION

The interest in protecting underwater cultural heritage has grown notably in recent decades [1–5] in response to the social interest demanded by the thousands of wrecks found on the seabeds and the huge amount of archaeological sites existing under marine waters. Proof of this interest was the international treaty of UNESCO Convention [6], especially dedicated to the protection of the Underwater Cultural Heritage. In Spain, its application involved the elaboration of a series of recommendations that were presented in the “Green Book” of the National Plan for the Protection of the Spanish Underwater Cultural Heritage” emanated from [7]. The current situation of this type of underwater heritage is reflected in the Green Book, underlining the shortage of professionals with scientific training. In addition, it should be stressed that much of the national and international scientific attention given to underwater heritage has been focusing on the marine context,

relegating to a second term the rich and abundant Spanish cultural heritage submerged in reservoirs [8–16].

A. Exceptionality and specificity of cultural heritage in reservoirs

Man has dammed water and built dams for thousands of years for various purposes [8]. In Spain there are 1,230 reservoirs, being the fifth country in the world with the largest number of dams (with a total of 7,000 reservoirs in the world [16]), and the first in Europe.

The construction of these reservoirs meant the flooding of numerous hectares of land that often included occupied settlements, with more than 500 submerged settlements existing in the Spanish territory (again occupying the first place at European level).

Despite the high number of cultural heritage elements flooded in Spanish dammed waters, there is not a complete catalog. But, what concerns the most is that scientific knowledge about its state of conservation and the deterioration to which it is exposed is much more limited, or practically non-existent.

Another peculiarity that encloses underwater heritage in reservoirs is the frequency at which they must undergo dredging and emptying processes. In some countries, such as in France, total emptying of reservoirs is a regular and regulated practice: once a decade. In the case of Spain, the poor state of the drains and the need for their repair makes the emptying of a reservoir an equally frequent practice. In other cases, the emptying is not temporary, but definitive and scheduled.

From a scientific point of view, the analysis of the deterioration of the marine underwater heritage and the study of its conservation and durability can be partially applied to the context of inland waters, although, the great particularity of the heritage submerged in reservoirs is that it is more exposed to very sharp and frequent rises and decreases in the water level (months, years) as a result of consecutive and alternate periods of rainfall and droughts - both increasingly extreme - frequently

resulting in episodes of outcropping (partial or complete) of the cultural heritage elements. In this context, concepts and processes already studied in subaerial built cultural heritage under conditions of capillary rise of water can be applied. Goudie [17] defined the term wick effect to refer to the capillary rise of water with salts in solution inside a wall stone, which leads to salt crystallization processes, intensified by wetting and drying cycles. The crystallization of salts inside the porous materials is one of the main causes of deterioration [18], and can often lead to their total disintegration and complete loss of the material.

As already known in the field of Heritage Science, one of the most important causes of the degradation of cultural heritage is the change in the conditions in which the cultural heritage item is found specifically. And this change of conditions - from underwater to sub-aerial - is the one facing cultural heritage in dammed waters in a cyclical and recurring manner, especially lately during frequent periods of drought.

B. Impact of climate change on the deterioration of cultural heritage in reservoirs

Sabbioni et al. [19] addressed this issue, of renewed relevance and impact, since in recent years some submerged sites have emerged, as a result of the notable decrease in water level in reservoirs due to the increasingly extreme seasonal droughts.

An example of great relevance is the prehistoric site of the Dolmen of Guadalperal (Cáceres) - known as the Spanish Stonehenge - (Fig. 1), which presents a very important megalithic complex that remained submerged under the Valdecañas reservoir since the construction of the dam in 1963. Although drought is a frequent phenomenon in the Spanish climate, after the drought of 2019, the damage to the monument could be observed, and actions for its conservation and protection were launched, although the site is reachable only by boat.

The effects of climate change manifest themselves worldwide. A spectacular example is that of the 400-year-old Catholic temple that saw the light again after more than 50 years under the waters of the Malpaso dam in Chiapas (Mexico), after the drought recently affected the area and that lowered the water level more than 25 m.

Climate change, thus, acquires a decisive role in the deterioration of the continental underwater heritage, since it increases the frequency of both floods and droughts, also providing for an intensification of these effects in the coming years.

What is a proven fact is that there are numerous European regions that already suffer from very extreme floods and droughts, as reflected in the European Environment Agency report [20]. Regarding the Mediterranean region, this report foresees the increase in heat waves, the decrease in rainfall and river floodings,

the increase in the risk of droughts and in the demand for water for agriculture, and competition between different water users.



Fig. 1. Dolmen of Guadalperal, Spain.

C. State of the Art

There are few and very recent investigations addressing the heritage submerged in reservoirs. In Spain we find the research by Matamoros [13], limited to a specific region case and more focused on other issues than on research.

At an international level there is a research [15], which provides a more scientific approach and a specific case, attributing the deterioration fundamentally to the effect of waves, wind, biological activity and ice-thawing processes.

Regarding scientific papers, most are related to the management of this type of heritage, the social consequences, impacts on the cultural landscape, destruction of built heritage, legislation [9,11], and to the mitigation of damage to cultural heritage caused by the construction of reservoirs [10].

Scientific contributions of cultural heritage submerged in inland waters (which includes all types of inland waters and mostly river environments) have been presented in different editions of the International Congress on Underwater Archeology-IKUWA.

II. PROJECT JUSTIFICATION AND WORKING HYPOTHESIS

The working hypothesis of this project is the absence, and pressing need, of an *ad hoc* scientific methodology in order to address the analysis of the deterioration of stone constructions of cultural heritage located in dammed water environments.

The project justification of the working hypothesis is supported by the following aspects:

1. The huge amount of cultural heritage located in inland underwater environments, mainly in reservoirs, and the alarming threat that exists on its deterioration and eventual loss.

2. The scientific void that exists on this subject, compared to the knowledge acquired about marine

underwater environments, not even knowing what is the casuistic that affects this specific type of heritage.

3. The weather conditions recently associated with climate change, which are causing part of this heritage to emerge / partially or completely, due to very abrupt variations in the water level of the reservoirs, which result in the emergence of a new transition sub-environment included between the other two (underwater and subaerial), and that is the one that is at imminent risk of complete and irreparable loss.

4. In addition to the advances in knowledge that the results of this project can provide in this relatively virgin field of research, essential data are made available so that, if they deem it appropriate, the responsible institutions can develop protection regulations, thus avoiding the high current risk of irreparable loss that exists.

5. The scientific methodology to be developed in this project is, according to the bibliographic review carried out, novel (especially that regarding the subaquatic survey) and would be extrapolated to any similar problem related to the deterioration of cultural heritage in inland dammed waters worldwide.

III. OBJECTIVES

The general objective of this project to achieve in the following 4 years, is the analysis of alteration processes of stone material from cultural heritage in environments of inland dammed waters in process of emersion.

The specific objectives to achieve are the following:

1. Analysis of the constructive, geological and environmental conditions that intervene in these sub-environments, emphasizing the intermediate sub-environment, between the underwater and subaerial ones.

2. Analysis of the alteration pattern and the deterioration processes in heritage stone structures / elements located in the reservoir bed and subject to the conditions of the sub-environment that suffers from rapid rises and falls of the water level. Comparisons will be made with the two other sub-environments that coexist: the underwater or submerged in water and the subaerial or emerged. The analysis of the deterioration processes that has taken place in the past, and those that are currently occurring, will allow the prediction those that will take place in the future. In this specific objective the technological development of instrumental techniques to be used in subaquatic conditions will be also performed.

3. Development of a scientific-technical protocol for the analysis and monitoring of cultural heritage stone elements subjected to cyclic partial immersion-outcrops in inland dammed water environments, as well as a mathematical model for future prediction.

IV. CASE STUDIES

Two case studies have been selected. The criteria for their selection have been based on the following aspects:

- Each case is made with different stone materials.

- The waters of each of the selected reservoirs are located in geological environments eminently carbonatic (alkaline) on the one hand, and silicic (acidic), on the other.

- Both cases are currently experiencing episodes of partial outcrop of the built cultural heritage.

- In both cases there is a construction or relevant constructions built in traditional stone and techniques of the area, with the sufficient height that allows differentiating the three sub-environments.

- Both cases belong to the same river basin (Tagus river), which will facilitate authorization or permission issues.

The two case studies selected based on these criteria are:

- Case study 1: The Royal Site of La Isabela (Fig. 2), built at the beginning of the 19th C. as a city-palace and spa of the royalty and nobility of the Enlightenment. The main construction materials are limestone and sandstone. The site was flooded in 1955 by the waters of the Buendía reservoir, Guadalajara (with eminently alkaline waters), and is currently in a state of ruin and abandonment, without any protection. The construction of the Tajo (Tagus)-Segura rivers transfer and its set up at the end of the 70s, as well as the periods of drought of recent years, have caused the water level to drop in summer until partial or total exposition of the constructions of the site.

- Case study 2: El Burguillo reservoir, in Ávila, is one of the oldest large dams in Spain (1913). When the water level drops, the Arch's bridge appears, a bridge of medieval origin and rebuilt in the first half of the 17th C., as well as the bell tower of the old church. It is a granitic area.

V. SOCIAL AND ECONOMICAL IMPACT

The social and economic impact resulting from this project would be focused on the rural environment, more specifically in those municipalities where cultural heritage was flooded by the construction of dams. Many of these territories maintain a fight against depopulation, and seek mechanisms that encourage social, economic and demographic development. One of these mechanisms could be inland rural tourism in reservoirs, and in this respect, the so-called *drought tourism* already exists. Rural tourism must compete with all kinds of tourist destinations - UNESCO and the Spanish government warn that extreme drought can have a strong impact on Spanish tourism - so that an added value must be offered to attract the public. This added value would be the scientific knowledge of the deterioration that affects this type of heritage. Its value could be framed in a scientific-cultural tourism.

To ensure the long-term impact, and, in short, the

protection of this type of heritage, collaboration with regional institutions, councils and local administrations, and with those Public Administrations related to water management, climate change and cultural heritage would be required, taking also into account companies and professionals that develop in their respective fields an active and inland tourism linked to the reservoirs.



Fig 2. Royal site of La Isabela, partially submerged by the Buendía Reservoir (Guadalajara).

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