

EVOLUTION OF DESIGN IN BUILDING THE QUAY BREAKWATER OF THE DOCK IN CARTAGENA HARBOUR. PARADIGM OF 18TH CENTURY BUILDING KNOWLEDGE

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Abstract

The case study of the port of Cartagena set out in this paper is intended to demonstrate the scientific, technical and cultural value of these constructions and so to contribute to the study of the unknown Mediterranean underwater cultural heritage as a prerequisite and essential step towards the promotion of its value and conservation.

The need to erect an arsenal in the city of Cartagena during the 18th century required the construction of an artificial basin in the hidden Mandarache Sea.

This project involved a technical struggle against nature requiring the latest expertise for its construction at that time. The study of the designed building solutions, the techniques carried out and the organisational processes performed in these works prove that they are an example on applying the latest know-how at that time by some of the most prominent scientists and technicians in the country.

These works were performed by military engineer Mr. Sebastian Feringán Cortés in cooperation with sailor and scientist Mr Jorge Juan and Santacilia and further consulting with Mr. Antonio de Ulloa. Such significant underwater works in the Arsenal of Cartagena are stated in the records of the time. Mr Sánchez Taramas (1769) accounts them as unique and considers their study as utterly useful for training future engineers.

This article was performed upon the analysis of different historical dossiers found in the Simancas General Archive (Valladolid, Spain), containing manuscripts written by the architects responsible for the building work whose results achieved highlight their historical and technical value and can be applied to other works of similar features around the Mediterranean basin.

Keywords: Cultural Heritage/Ports/Maritime Engineering/Military Engineers/Conservation.

1. Research aims

The analysis of the case proposed aims to prove the scientific, technical and historical value of this type of works and so help promote the historical and archaeological study of our cities waterfronts. Proving the need for this type of study aims to do the following:

- a. Show the value of this historical heritage, occasionally forgotten, and restore its cultural value so that it is granted sufficient legal protection to protect the relevant elements of the continual adaptation work underway in these ports or “living organisms”. These works must be classified in accordance with International Architectural Heritage.
- b. Make the port area the centre of attention for cultural tourism in cities, not only for leisure and recreation, but to develop knowledge by revealing its history in the broadest sense, stressing the surprising nature of its architectural design and construction throughout history.
- c. Promote architectural construction studies on ports as an integral part of their management plans so that the actions considered respect and are coherent with the existing port, facilitating restoration and reintegration work in the city where necessary.

2. Introduction

The evolution of the project which resulted in the definitive approval of the building of the arsenal and port in Cartagena took place between the years 1670 and 1752. Numerous projects were drawn up, of which only a few were then approved as official projects for the building work to be carried out in the port of Cartagena in its successive transformation stages.

Minister for Maritime Affairs, D. José Patiño, took on the organisation of the Royal Navy, creating, with a law passed on the 5th of December 1726, the Maritime Departments for the North, South and East, the capitals of which were to be El Ferrol, Cadiz and Cartagena respectively. Arsenals were to be built in these locations, whose mission it was to maintain the necessary contingents for forming a capable navy.

The need to transform Cartagena’s anchorage for the storage and maintenance of the modern fleet, required three fundamental steps (Fig. 1): the construction of all of the buildings needed for the new military arsenal (1); the creation of an artificial basin in what was the hidden Mandarache Sea (2) and the creation of the first dry docks on the Mediterranean coast for repairing or careening boats (3), which were to transform the Cartagena shipyard into one of the most advanced naval constructions of that time.

These last two works, the basin and the careening docks, were to imply one of the greatest technical challenges for military engineering in the 18th century; both being taken as a reference for future building work below sea level. This is corroborated by the Head of Engineering, Sebastián Feringán, when he demonstrates its complexity to the marquess Marqués de la Ensenada in the explanation regarding the solutions to be adopted in the building of the quay breakwaters in the port of Cartagena [1].

[...]This company is one of the most hardworking you can find, and as there is no news of any other construction equal to this having been made in Europe, as the profile shows, a depth of 30 feet (9.75 m) below sea level must be reached in order to dig. Once this is done, we can say that the arsenal is finished, [...].

The construction systems and the procedures used in the dry docks are also taken as an example and contribute towards perfecting the systems used in existing docks in France and England. Sánchez Taramas bears witness to this in the following manner [2].

[...] it could be useful to show in this Addendum, the practice that has been carried out at the arsenal of Cartagena in order to establish different buildings in the water, particularly the docks, [...]; as well as being such unique building

works, which, with the exception of Spain, no other Mediterranean Sovereign has (although all of them would like to, due to their importance), this will greatly contribute to the accurate execution of this type of works. [...].

3. The construction of the quay breakwater of the dock in Cartagena harbour (1750-1764)

The conditions imposed by the monarch for carrying out this building work underwater were to guarantee its strength and durability, as well as it being used according to its purpose.

The solidity and permanence of the quay breakwater was achieved with the correct design of its foundations, a choice of materials that were appropriate for the location and the correct use of said materials. The desired functionality was then to determine that the final solution was to allow a dock to be created with the necessary depth for the draft of the ships and a geometry that allowed the vessels to approach correctly.

The construction designs drawn up with that purpose evolved as the knowledge of the surrounding environment advanced, along with the technical knowledge of the engineers participating in the process.

The first proposal of Alejandro de Rez to cover the quay with a breakwater in 1728 (Fig. 2) was then to be improved by Sebastián Feringán in 1733, who proposed a mixed coating made of masonry and ashlar, directly cemented to the base. Following several hiccoughs in the works, which proved that it was impossible to implement this solution, the engineer modified his initial proposal, improving the support systems and the dimensions of the wall (Fig. 3).

This theoretical model proposed by Feringán, was to be adapted to the geotechnical characteristics of the ground as the building work progressed and was to make the necessary dredging along its sides possible, without this posing a risk to the safety of the works.

Given the orographic characteristics of the area, the adaptation necessary to enable the quay breakwater to be built was to mean that each side of the quay would require a different solution. The ground on the north and east sides of the dock was built up by alluvial deposits from the incoming watercourse and the quay was to be cemented into them using a piling system. The west and south sides were to be built upon the rocky stratum at the foot of the nearby mountains, locating the stratum closer to the surface, allowing the quay to be directly cemented onto the base.

In spite of the fact that the ground had a good bearing capacity [3], the springs of water leaking into the excavations implied a constant challenge that had to be overcome in building work carried out below sea level [4]. It was this concurrence of water with the excavations and not the resistance of the ground, that would determine the need to turn to a deep foundation system, different from the original one planned (Fig. 3). Likewise, it would force the quay to be built using foundation trenches that, along with the construction of box caissons allowed the volume of water entering them to be controlled. The abundance of water in the excavations not only made it impossible at times to carry out the building work with the means of bailing available, but it also caused liquefaction to occur in the ground at the base of the excavation [5].

[...]; and not being able to advance, the water will not seek its level, and this way it will avoid the ground being swollen and dampened as, being of poor quality, the ground is very firm and the opposite occurs, no matter how little water enters, it all turns into a very runny sludge [...].

This occurrence was to be minimised by the piling driven into the base of the excavation that increased the directions in which the water could flow, causing its gradient to be reduced and so guaranteeing that the force of the water that could move the earth at the base of the excavation would be diminished.

Finally, on the north and east sides, it was decided that the surface of the foundations would be set at approximately 35 Spanish feet (9.75 m). On the west and south sides, close to the foot of the surrounding mountains, the surface of the foundations, made of tufa, can be found at 30 handspans (6.26 m) below sea level, varying slightly from north to south.

The origin of the water that floods the excavations was the object of great debate, as well as the effects that it may have had on the building work. Finally, it was concluded that their presence would merely hinder the execution of the quay during its construction, as the water would then go back to normal once the exterior wall of the platform was finished.

3.1. The need to turn to piling: the north, east and foremost quay in the natural harbour

The seabed in this area has been built up by fine alluvial deposits forming layers of quaternary sediment made up of sand, lime and clay.

The lithographic cross section in the north-eastern area of the works on the strata located within the area influenced by the structure, is verified by a dynamic penetration test carried out in the ground by driving in a 34 palm long stake (11.00 m) to the depth of 29.5 royal feet (9.53 m). The result of said test enables a stratigraphic description of the ground to be made and ascertains the suitability and strength of the ground for the foundations that are to be built [6].

[...]. The quality of the earth on the surface is loose soil, almost mud: lower down at a depth of 9 or 10 feet (2.50-2.80 m), where the soldier piles are driven in, it is more consistent; even more so at 20 and 22 feet (5.50-6.00 m) where the pile caps and cross timbers are driven in: and where the bottom of the soldier piles and piling go this is of course solid ground for two reasons: one, because the stakes will not go in any lower than 34 or 36 feet (9.50-10.00 m), no matter how hard we try; and two, because the Springs of water normally displace Small shells and Gravel, which can only happen on solid ground, as gravity always makes them sink to the bottom of soft ground. [...].

In light of the above description it can be concluded that the stratigraphy of this ground consists of three levels; level I from 0.00-2.50 m of sandy lime mud of a poor consistency, level II from 2.50-5.00 m made up of lime sand with broken remains of sea shells and gravel, becoming more compact the deeper we go, and level III from 5.50-9.50 m formed by sedimentary rock, more specifically stratified limestone, with a moderate hardness which is to be the base for the foundations of the building works.

However, it wasn't to be the admissible tension of the ground that was to determine the foundation system to be used, but the verified impossibility of controlling the water that flooded the foundation channels. This fact meant that they were forced to turn to a deep foundation system using piling on the north and west sides [7].

[...] the piles stay in place, ready to position the pile caps and cross timbers upon which the works are to sit, the use of which I haven't been able to avoid, as for fear of the effect of the spring water, I have only gone down 32 handspans (6.68 m) and the rest is made up for by the piles [...]

Such circumstances meant that it was impossible to base the first row of ashlar of the quay at the depth established, making it necessary to rethink the construction system that was initially planned. Now it would be necessary to limit the base of the excavation to 32 handspans (6.68 m) and build a wooden grid at this level upon which the ashlar construction would be supported [7] (Fig. 4).

The description of the construction process that ensued in order to produce the first caisson using piles (Fig. 5) is clearly set out by Jorge Juan in the report that he sent to the monarch [8].

Activity 1. Excavation: Movement of earth via manual means to obtain an open sloped trench, the depth of which is limited to the level where the water comes to the surface at the base of the excavation (4.23 m) [9]. This task is accompanied at all times by bailing using manual pumps that are placed in the trench itself.

Activity 2. Sheet piling: A retaining system driven into and supported in the base of the excavation, made up of chamfered piles and tongued and grooved wooden planks. Their double purpose is, on the one hand, to improve the watertightness in the bottom of the trench by dividing it into caissons that limit the influx of water, which it is then possible to remove using

the pumps and, on the other hand, to provide the necessary shoring to be able to excavate at the depth at which the piles were to be driven in.

Activity 3. Piling: Pine piles with a square cross-section in staggered formation driven into the base of the excavation until sufficiently firm (10.44 m) [7].

Activity 4. Earth removal: Extraction of the earth between the sheet piling via manual means to uncover the heads of the piles.

Activity 5. Creation of a grid: A horizontal grid built using orthogonal elements of pine wood, the points where they cross being located upon the heads of the piles. This grid is made up of meshed wooden bolsters which are placed on top of the piles at right angles to the quay. Further meshed wooden beams or timbers are placed on top of this. Piles, bolsters and timbers are braced at the cross-points using reinforcing oak bars and the meshed formation of the beams in the grid.

Activity 6. Filling: The space below the grid and any gaps are filled with a mixture of pozzolana, lime and aggregates, which are then compacted and leveled with the top side of the beams, making a solid and level foundation upon which to start the building work.

Activity 7. Production of ashlar for the elevation: Placement of the ashlar or sandstone blocks to form the exterior wall of the quay, filling the joins with mortar made up of lime, pozzolana and ground brick.

Activity 8. Production of the ashlar for the top and moorings: The three last rows of the wall were to guarantee its durability against the elements to which it was exposed upon rising above the water level, as well as the adverse effects caused by the traffic of the port itself. To ensure this, “*Alicante stone*” was used for the penultimate and antepenultimate rows and “*Strong stone*” to provide a superior finish to the quay. The rings placed for mooring the ships were fitted under this last layer, anchored to supports built into the backfill of the wall.

Activity 9. Construction of the platform: Once the retaining wall was complete, the backfill was filled with earth from dredging the dock and the trenches that were opened to build the foundations of the buildings. Once the level was reached and the filling compact, the platform was paved with cobblestones made of “*Strong stone*”.

Activity 10. Dredging of the dock: This work was carried out by hand in front of the finished quays, where earth trenches were used to keep the sea at bay. Whilst this work was being carried out in front of the quays, pontoons and dredgers removed the central earth from the dock to outside the port. Once the quays were finished, the earth trenches retaining the water were to be destroyed and the waves were able to crash upon the newly built quay.

3.2. Foundations built directly upon the rocky sea bed: the west and south quays

The west and south quays were to be built with their foundations resting directly upon the sea bed (Fig. 6) where the top of the foundations is closer to the surface of the sea. After manually excavating the sandy lime levels I (0.00-2.50 m) and II (2.50-5.50), the rocky limestone strata of tufa, which also forms the nearby mountains, are reached [10].

[...] and in this place it is established, on natural ground of calcrete with a surface layer of stone, with an amount of water that can be overcome, and it is partially compressed and held in place with the weight of the ashlar blocks that have been set[...].

The building of the foundations was simplified and was limited to driving in the soldier piles forming box caissons from which it was possible to extract the ground water and place the first row of ashlars upon a layer of pozzolana spread directly over a 3 palm (63 cm) trench opened up over the limestone rock [11].

[...]. In the western angle, the spring water is abundant in that part of the ground, due to the untouched earth that is found there made of clay and a covering layer of soft stone that needs petrifying, and we will go three handspans down into it,

where the first layer of ashlar will be placed with pozzalana, 20 Royal feet below sea level which make $23^{1/2}$ Spanish feet [...].

4. Conclusions

The work carried out in Cartagena for the construction of the dock which would transform its port during the 18th century, went on from the 20th of May 1750 to the 1st of January 1764. This port infrastructure still stands today, having conditioned the subsequent urban development of the city (Fig. 7). It was a project that involved unprecedented technical challenges and the greatest investment made into the adaptation of the port throughout its history. However, this is still unknown to the citizens this very day and has no legal protection to guarantee that it will be valued and conserved with the passing of time. Nonetheless, in view of the research carried out, the following conclusions can be drawn:

1. It can be declared that the work which represented the greatest technical and scientific challenge among all the work carried out in order to transform the port of Cartagena in the 18th century is the creation of its artificial dock.

The complexity involved and the interest arising from its design and construction are determined, among other things, by the depth under the sea at which the foundations had to be built and the proximity of the excavations to the sea. The inrush of water through the perforations in the works that were underway was to determine its design and would complicate the process, which was finally to be resolved with the skill and mastery of the military engineers in charge of the works.

2. The work carried out for the construction of the dock in Cartagena is a challenge for the technology of the time when it was built and was not a result of said technology.

The decision to build the dock for the arsenal of Cartagena was independent of the existence or lack of the contemporary technical means and knowledge of its time, guaranteeing that it would be possible to build. The decision was adopted for geostrategical reasons and it would be necessary that technology evolved in order to see it through. It would be necessary to perfect the auxiliary means at hand in order to complete it (sheet piling, pumps, bolsters and trip hammers) and to apply some particular construction solutions, which when put into practice using the appropriate procedures, allowed the construction of the artificial dock under the existing determining factors.

3. The port legacy that the city of Cartagena has received from the 18th century, designed and built by military engineers, is worthy of being divulged given its scientific, technical and cultural value.

In this article the patrimonial value of the illustrated port legacy of the city of Cartagena is made evident, as well as the convenience of publicising it as a factor of knowledge development based on its historical, architectural and technical value. It is considered to be an opportunity for the local and regional environment to develop its potential as a tourist attraction, in such a way that the port goes beyond just being a place of leisure and relaxation for the city, complementing the city's range of cultural tourism.

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Captions for figures

Fig. 1 – *Plan of the project to construct a navy Arsenal in the Port of Cartagena.*

Not dated [Approx. 06/04/1751]. S. Feringán

A.G.S., MPD 21, 011 (Marina, Leg. 376). Ministry for Education, Culture and Sport. Simancas General Archive

Fig. 2 – *Cross-section showing how the Ashlar blocks for the Exterior of the Pier are to be laid.* 21/11/1731. A. Rez

A.G.S., MPD 16, 038 (Marina, Leg. 375). Ministry for Education, Culture and Sport. Simancas General Archive

Fig. 3 – *Cross-section of line RQ of the Plan of the Quay of the Dock, showing its construction, base position where the foundations are to be laid and the distance of the building according to the Gen. Project.* 02/12/1749. S. Feringán

A.G.S., MPD 06, 086 (Marina, Leg. 377). Ministry for Education, Culture and Sport. Simancas General Archive

Fig. 4 – *Cross-section of line 1.2. of the Quay and Warehouses on the east side of the Port, in which the current stage of construction of these Works is shown and the water depth is marked with numbers in Spanish Feet.* 16/01/1753. S. Feringán

A.G.S., MPD 22, 012 (Marina, Leg. 322). Ministry for Education, Culture and Sport. Simancas General Archive

Fig. 5 – *Stages of the construction process of a caisson with its foundations upon piling.* Source: Created by the authors

Fig. 6 – *Cross-section of the state in which the first box caisson was to be found on the 9th of August in the south side of the*

Dock. 09/08/1758. S. Feringán

A.G.S., MPD 38, 118 (Marina, Leg. 328). Ministry for Education, Culture and Sport. Simancas General Archive

Fig. 7 – *Current appearance of the port of Cartagena.* 20/01/2012

Source: Google Earth