Underwater Construction in the Eighteenth Century: the Royal Arsenal in Cartagena - an Extraordinary Case

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INTRODUCTION

When the Bourbons came to the throne in Spain in 1713 great reforms were initiated in the organisation of the Spanish Navy, which coincided with each of the reigns of that period. The aim of these changes was to encourage the development of the Spanish Navy in order to reach the standards of the English, French and Russian Navies. A momentous reform for the city of Cartagena came about in 1726, during the reign of Phillip V, namely the division of the Spanish coast into three regions: El Ferrol, Cadiz and Cartagena. In each of the capital cities of these regions, an arsenal was built which was not only responsible for the building of new ships, but also for equipping, repairing and adorning the vessels belonging to that area. El Ferrol extended its jurisdiction from the French border to Portugal; Cadiz, from the Portuguese border to Almeria and the Canary Islands; Cartagena, from Murcia to the French border, also including the Balearic Islands.

The construction of an arsenal in a city like Cartagena entailed important changes in urban development, as well as geophysical, social and economic changes, that still exist today, but these are not the objective of this study. The aim of this paper is to show the technical and scientific development achieved in the design and construction of this "proto-industrial complex" (Pérez Crespo Muñoz, M. Teresa 1992, p. 22), to which numerous engineers applied the most advanced technical know-how of that time.

José Luis González states that:

> Construction know-how is that which presents methods to the architect enabling him to optimize the results of varying ways of constructing while faced with a complex group of requirements that contradict one another […].
>
> (González Moreno-Navarro, Jose Luis 1999, p. 17)

Likewise, he asserts that *constructive knowledge* can be divided into:

- "That which provides the necessary information for the development of buildings"
- "That which is necessary for the building to become a physical object"

In any building work there are clearly marked stages. The first being a conceptual or project phase with the aim of adapting a functional programme and transforming necessities to certain determining factors; the site, technique, materials, the budget, and other materials or construction factors targeted towards the materialization of the project. During each of these stages different aspects of the process of bringing a real construction to life are revealed. In the first, the skill involved in the design, and in the second, the use and command of the materials, as well as the techniques. In this case we shall be paying attention to the second of these and, more specifically, to its initial phase which involves the laying of the building's foundations. There main reason for choosing this particular phase within the construction process of the arsenal is that we consider this phase of the building work to have presented the greatest technical and human challenges, which have been resolved with skill and mastery by the military engineers responsible.

The complexity and interest involved in the building methods of the Royal Arsenal in Cartagena are determined, among other things, by the particular conditions of the construction site and the circumstances in which the work was carried out. The key determining factor was the depth below sea level at which the foundations of a number of constructions had to be laid (quays, dry docks, buildings, storerooms, workrooms, etc.), in the absence of the tides which could have made this work easier, as was the case with arsenals built in France and England, where the ocean tides facilitated the execution of the building work.

In order to achieve this in the arsenal at Cartagena various systems were used for laying the foundations underwater. These deserve special attention and the methods adopted will be compared with the systems and means recommended in the various construction treatises of that time. In this way we shall learn about the references that the chief engineers worked with and the technical advances that were introduced into this field with a double purpose: to influence architectural and historical value judgments and to facilitate restoration work and reintegration of the historic complex into the city where necessary.

APPROACHES TO THE LAYING OF FOUNDATIONS UNDERWATER IN EARLY FORTIFICATION TREATISES

Fortification treatises (sixteenth - eighteenth century) were guidelines for military engineers and also contained solutions for various technical problems such as those encountered in the laying of foundations. Given the diversity of land types and their properties it was deemed necessary for building engineers to have a solution for each particular case.

The classification of types of land in fortification treatises corresponds to two main groups: wet and dry. Within the first group we can find wetlands, the seabed, riverbeds, riverbanks, the seashore, the shores of islands. In the second group: sandy, clayey and rocky land. At first glance, the solutions for some of these conditions appear to be similar, however, there is no doubt that the historic

exponents of the subject attempted to exhaust all possible options, so that the engineer had a wide range of possibilities when faced with any type of land. As Pfeffinger (Pfeffinger 1713, p. 229) affirmed regarding building on wetland: "these places are of varying kinds, such as lakes, ponds, deep brooks, shallow rivers, and building work cannot be carried out in the same way in all places." The main problem faced by contemporary engineers in this respect was the construction of the foundations underwater, as well as their repair due to the devastating effect of the waves beating upon them. On this matter, González de Medina Barba (González de Medina Barba, Diego 1599, p. 140) observed that, "making strong foundations underwater is difficult, but is done well and in different ways."

Several construction procedures for laying foundations on wetland are described in detail in the fortification treatises, including problems that may arise in the event of an incorrect construction procedure. In this case we are focussing on the most elaborate construction process, the laying of foundations underwater and different ways of carrying out this work.

The recommended methods of foundation laying on wet land are: using loose stones, with boats or caissons, using floating caissons, with cages or gabions, with caissons following the method used by the French, and using piles. We can further classify the different historic systems for laying foundations on this type of land according to the possibility or impossibility of draining off the water, so as to be able to carry out the building work. There are systems that aim to bring the height of the foundations to above sea level, or above the surface of the water as in the case of seas and rivers; others which seek to transmit the load of the structure to deep load bearing layers in the ground, since the soil where the construction is situated does not have sufficient load bearing capacity in the uppermost strata, as is the case in wetlands.

Foundation laying methods where it is impossible to drain off the water

All procedures used in underwater construction, as seen below, represented various alternatives for attaining a common goal: to create a solid and level platform which is supported at the base and allows foundations to be laid upon it at the height above sea level established by the water level at high tide. The following guidelines are given in the treatises:

Method using loose stones **(fig. 1)**

Excavation and layout:

> When it is a question of building in water and constructing masonry walls, the design will first be laid out on the water, by driving in thick piles all over the design.
>
> (Fernández de Medrano, Sebastián 1696, Libro III, p. 163)

The marking out for the creation of the platform that will serve as a base for the foundations of the walls will be carried out making the most of low tides and using wooden piles, which are driven into the sea bed so that they indicate the perimeters of the construction that is to be built.

The base of the foundations:

This will involve the creation of a stone berm upon which the foundation base will be supported. These stones are transported in boats to the place marked out earlier and will be set in place in successive layers alternating with layers of lime mortar with puzzolana until water level at high tide is reached. The largest stones will be placed on the exterior incline of the pavement so that the works are protected from the beating of the waves.

Construction of the foundations:

Regarding the construction of the foundations, this will be achieved using stones selected by size so that the largest are placed at the base of the foundations and levelled in such a way that they make a support plane for the wall.

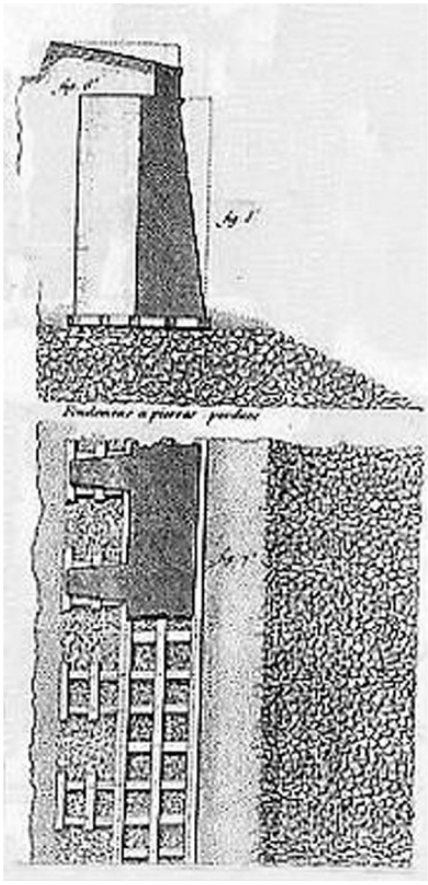

Figure1. Method using loose stones (Forest de Belidor, B. 1729)

Boat or floating caisson system **(figs. 2 and 3)**

Excavation and layout:

For the layout of the foundations the same procedure will be followed as in the loose stone method.

The base of the foundations:

> Having found the place and seen the capacity it should have, have as many boats made as shall form the grounds; and said boats shall be made without a point at the head, in the shape of a large box, in the centre of which a hole shall be made, that is to be closed with a long log superior to the height of the boats. Afterwards I wish to make the foundations in these boats with long, thick stones. And I move one boat close to the other, holding both the stones and the boats together with good metal bars […].
>
> (Maggi, Girolamo; Castriotto Fusto, Giacommo 1564, Libri tre, p. 81)

> Caissons shall be put in place that have the same width as the wall is to have, well caulked, and joined together, leaving openings in the top and bottom at equal distances, in order to place large stones, iron crosspieces, and pieces of wood inside them to stabilize them […]. All of the caissons used for this purpose are joined together and filled with masonry […]. Note that if the water is deep the surface of the water will not be reached with only one such frame, then another shall be made as above to be placed on top of the first… due to the weight of the masonry the bottom will have come out, so that the centre of each of the second caissons will fall onto the joins of the first […]
>
> (Fernández de Medrano, Sebastián 1696, Libro III, p. 164)

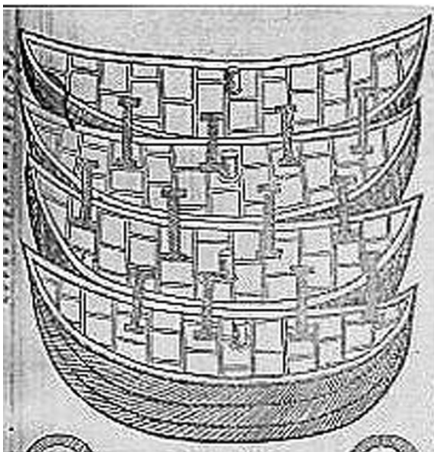

Figure2. Boat system (Maggi, G., Castriotto Fusto, G. 1564)

The use of boats or caissons in the fabrication of the pavement is intended to solve the problem of deterioration of the latter due to the loss and detachment of materials caused by the beating of the waves. The procedure involves using boats or caissons that are filled with stones and mortar so that the latter sets underwater. These boats are moved on the surface and are then allowed to sink in the place marked, ensuring that they remain connected via metal bars so that a solid and level ground is formed. The caissons are placed to form an initial base, one beside the other, and then upon a second level one on top of the other until reaching the desired level for beginning to lay the stone.

Construction of the foundations:

Regarding the construction of the foundations the same criteria shall be followed as set out in the case above, that is, they will be made with stones selected according to size.

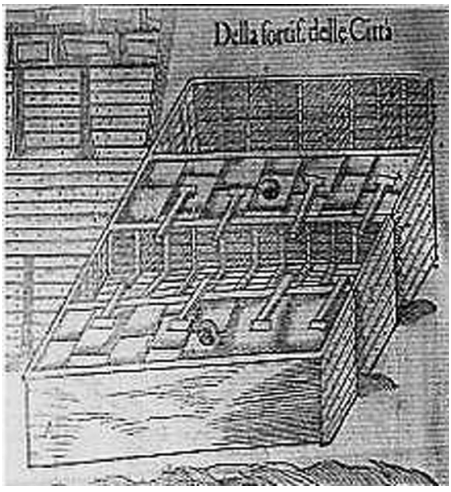

Figure3. Floating caisson system (Maggi, G., Castriotto Fusto, G. 1564)

Cage or gabion system **(fig.4)**

Excavation and layout:

For the layout of the foundations the procedure will be the same as in the systems discussed above in the case of underwater construction.

Base of the foundations:

To achieve the desired level for the base of the foundations wooden cages will be used with a folding bottom. These cages are filled with stones and mortar so that, when full, they can be anchored in the place set out and once the mortar has set the cage will be removed having served as

a recoverable formwork. This operation will be repeated as many times as necessary until the base reaches the width of the wall and the desired height.

Construction of the foundations:

The foundations will be made from stone selected according to size.

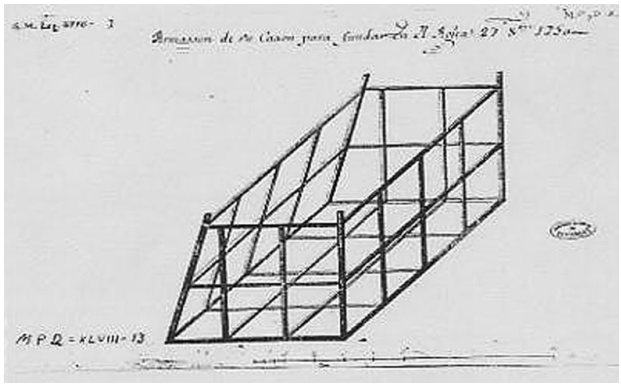

Figure 4. Construction system of a cage (AGS, M. P. D., XLVIIII-13)

Foundation laying systems where it is possible to drain off the water

All procedures used in underwater construction, as seen below, represented various alternatives for attaining a common goal: to create a solid and level platform which is supported at the base and allowed foundations to be laid upon it at the height above sea level established by the water level at high tide.

Method where caissons are filled in situ **(fig. 5)**

This method originated from the application of the boat or floating caisson system where the depth at which firm ground can be found is not very great. These circumstances allowed the water to be drained from the excavation as well as the construction and filling of the caissons in situ.

Excavation and layout:

For the layout of the foundations the same procedure will be followed as in the abovementioned systems for underwater construction.

Base of the foundations:

Once the perimeters of the foundations have been set out, a palisade is made around it, which prevents water from entering. This palisade will be made with stakes that are joined together and

lined with caulked boards. The water that remains inside the staked out area will be bailed out by means of various manual tools (tread wheels, tympanums or Archimedes screws), or using buckets. Once the water has been removed the base is cleaned until solid ground is found upon which the excavation will be filled with masonry. If solid ground is not found, some authors advised inserting another caisson, which is driven in until the ground is found:

> then the sand and the gravel inside the positioned caisson will be cleared: and if, the base of the stakes having been cleared, solid ground has not been reached, in this case another caisson will be placed inside that one, with a second lot of stakes with metal spikes added to them; so that by hitting them hard using mallets, they will reach the surface of the foundations: once the second caisson is in place, and well positioned, all of the sand will be cleared away, and solid, level ground will have been reached, […].
>
> (Rojas, Cristóbal de 1598, pp. 94-95)

However, if the seabed is rocky it will be necessary neither to clean nor to make the base of the foundations any deeper. Instead, the base will be levelled using pieces of timber with iron spikes and a bottomless caisson will be placed on the levelled seabed, from which the water will then be drained and which will then be refilled with gravel and mortar until reaching the surface of the water.

Construction of the foundations:

The foundations will be made from stones selected according to their size.

Figure5. Method where caissons are filled in situ (Forest de Belidor, B. 1729)

Caisson system following the French method

Excavation and layout:

For the layout of the foundations the same procedure will be followed as in the abovementioned systems for underwater construction.

Base of the foundations:

Once the perimeters of the foundations have been set out, a palisade is made around it preventing water from entering. This palisade will be made with stakes that are joined together and lined with caulked boards. The water that remains inside the staked out area will be bailed out by means of various manual tools (tread wheels, tympanums or Archimedes screws), or using buckets. Once the water has been removed the seabed will be cleared until solid ground is reached upon which a wooden gridiron will then be fixed into place with stakes in the corners of the cells. The spaces remaining between the top of the piles holding down the wooden gridiron and the grille will be filled with hydraulic mortar mixed according to the measures recommended by Müller:

> With this preparation you have a type of mixture or mortar, called Bitumen, made up of twelve parts puzzolana, or Dutch clay, six parts of good sand, nine of quicklime of the highest quality, thirteen of fine gravel, or rough stones no larger than eggs, and three of slate dust, or ash from limestone furnaces in which stone coal is burned, or of slag.
>
> (Müller, John 1769, Tomo II, p. 50)

Once the mortar has been made, it is left to set and once hard it is broken up with a pickaxe. With the help of a tray with a foldable base the pieces of mortar are lowered to be deposited in alternating layers upon the successive layers of stone deposited on the gridiron. Proceed in this manner until reaching the water surface.

Construction of the foundations:

The foundations will be made from stone that has been cut, positioned and selected according to size.

Piling system (figs. 6 and 7)

When it is impossible to use the caisson system due to the excessive depth at which solid ground can be found upon which to support the foundations, a system of foundation laying using piles is employed. This system is based on reaching solid ground at a depth by driving in wooden piles that will reach the desired stratum of the subsoil.

Excavation and layout:

For the layout of the foundations the same procedure will be followed as in the abovementioned systems for underwater construction.

Base of the foundations:

From studying the different methods of foundation laying using piles set out in the treatises consulted, we concluded that two different methods existed for the laying of such foundations. The first begins by a wooden grid being set in place covering the entire foundation area, with piles driven in within this cellular framework. To secure the foundations it is also necessary to place piles around the grid, driving them in side by side. The spaces remaining in the cells are filled with stones and then the stone ashlar of the foundations is set in place The second method commences by driving in four rows of stakes inside and out, once the width of the foundations has been plotted, following its shape including buttresses and putting in two piles in which the cells of the grid will be. When driven in and levelled, the grid is put into place, the joins being perfectly adjusted and fixed to the tops of the pilotis.

Once the wooden grid has been firmly fixed onto the piles driven into the subsoil, the spaces that remain between the heads of the piles and the wooden crossbeams are filled and an oak platform is made on top and secured before proceeding to make the foundations, as Mallet explains:

> When the foundations of the wall have been driven in, they are filled with […] pebbles, or loam, […] that is between the heads of the piles, then with strong planks which will form an oak platform, if it can be done, the heads will be joined together, all with good straps and iron nails. This way of joining the piles is called a trellis or grille […].
>
> (Manesson Mallet, Allain 1672, p. 68)

Some elements to be taken into account in the construction process when laying foundations with piles are:

- To leave the heads of the piles that driven in approximately a foot above the ground.
- There should be a distance of 2 feet between them.
- The length of the pile is relative to the resistance of the ground and the thickness of these may be between 13 and 16 inches.

The mortars used in filling in the grid are basically a mixture of lime, sand and gravel. However, Girolamo Maggi (Maggi 1564, *Libri tre*, p. 86) mentions the use of "concrete", remembering old building methods: "[…] and filling the space with concrete; and on top thick square stone, or with brick, as they did in the past". Marchi (Marchi 1609, *Libri tre*, p. 17) advises the use of pieces of

coal for the base of the foundations before putting the gridiron in place, and recommends covering this afterwards with an enamel made up of concrete, water and sand

> Belidor holds that there is a relationship between length and diameter of the piles, in which the latter could be a twelfth of the length. However, this rule cannot be applied to small piles of 6 to 12 feet in length. For those with a length of 18 to 20 feet it is sufficient to give them a diameter of 13 to 14 inches.
>
> (Belidor 1729, *Tomo I., Libro III*, p.57)

Construction of the foundations:

The foundations will be made from stone, which has been cut, positioned and selected according to size.

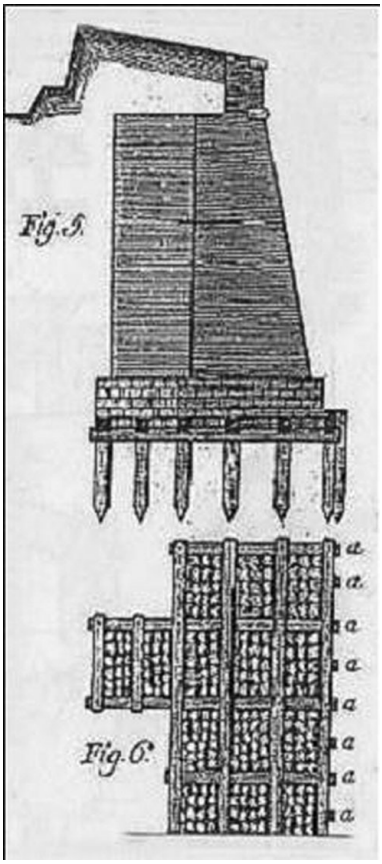

Figure 6. The first foundation system using piles (Müller, J. 1769)

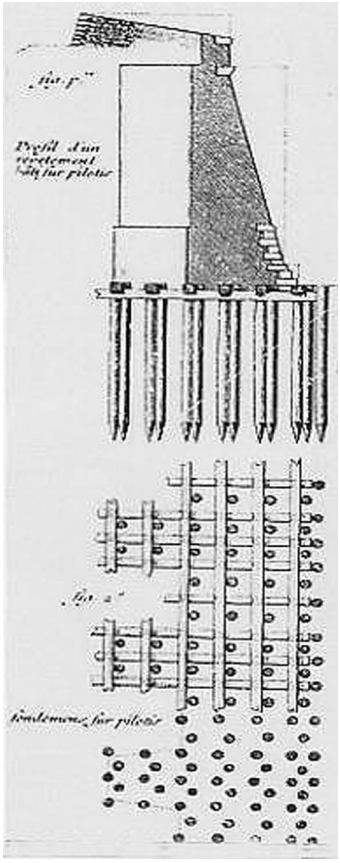

Figure 7. The second foundation system using pilotis (Forest de Belidor, B. 1729)

UNDERWATER CONSTRUCTION AT THE ROYAL ARSENAL IN CARTAGENA

According to Cañavate, the building of the arsenal in Cartagena began on the 20 February 1731, and the great work was finally completed on the 31 January 1782, when Charles the III was on the throne (Cañavate 1971, p. 85), but we should take into account a previous phase before the city was declared head of the region, when explorations were carried out to built a base in the city for the galley squadron.

Thus we have established a First Phase (1670-1726), before the regions were formed, which saw the creation of an anchorage where the royal squadrons over-wintered; a Second Phase (1726-1749), when a much more ambitious project was started, the construction of an arsenal. During this phase the position of the docks as well as the location of the buildings were decided and preparatory work started for the definitive building project, such as the cleaning and dredging of the inlet and the diversion of the watercourses that flow into it. Finally, a Third Phase (1749-1782), which corresponds to the effective execution of the definitive project for the arsenal that saw a new service added, the shipyard.

Preliminary studies (1670-1726)

In 1670, Lorenzo Possi received the order to design a port for the Spanish galleys at Cartagena, giving rise to the first known plan for its construction. Possi used the area of the bay situated at the foot of the castle and completed the pier, built at the end of the sixteenth century, which until that moment had served as the city's commercial port, and a breakwater which protected the vessels **(Figure 8)**.

At the same time, Luis Viller Langot proposed another alternative, which would be reintroduced in later years in the building of the arsenal, which was to create an artificial dock in the hidden Mandarache Sea next to the Galeras chapel, in the lee of the similarly named mountain to shelter the squadron of galleys.

Preparatory work (1726-1749)

In 1726 Cartagena was named head of the Mediterranean maritime department, although it actually only became active several years later, when it was decided that an arsenal should be built. The first design (SHM, Sign. 2636-2) was put forward on 30 November 1728, by the engineer D. Alejandro de Rez, who died before the building work was carried out. In this design the arsenal port was located in the Mandarache Sea to the northwest of the city, as Langot had proposed years before, and recommended the coexistence of this military port with the commercial port, both sharing the same entrance.

Rez's design took one important further step, considered to be a fundamental factor for the establishment of a naval base in el Mandarache, namely, the dredging of the arsenal dock and the

creation of a canal with enough depth for high volume vessels which connected el Espalmador Grande to the new dock. On 2 May1731 Rez produced a new design upon the request of the authorities in order to amplify the original so that all necessary buildings could be included, thus forming a marina, and completing the first stage of the arsenal's design (AGS, M. P. D., VI-93).

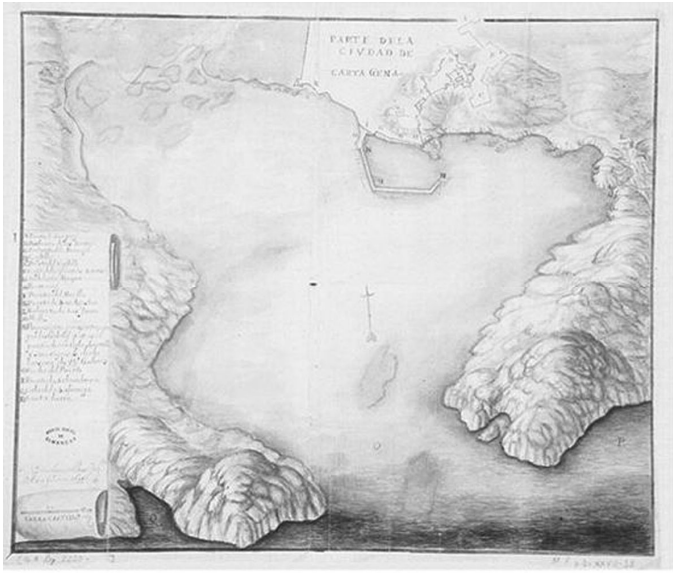

Figure 8. Plan for the building of a port for the galleys (Lorenzo Possi 1670, AGS, M. P. D., XXVII-33)

The definitive design and its construction (1749-1782)

In this final stage of the building of the arsenal the clearing work, dredging and diversion of the watercourses followed their course, and the position that was to be occupied by the dock of the arsenal also became clear. But there were different proposals that had to be sorted so as to clarify the dimensions and geometry as well as the final layout of the buildings. The following new plans were produced in 1747: Feringán, 10 June; Autrán, 18 June; Cosme Alvarez de los Rios 30August; Autrán again, in September; Superviela, general report 1 October (AGS, Marina, leg. 377, 11 July 1747).

In 1748 Autrán's design was approved, and shortly afterwards, in May 1749, Feringán returns to direct the building work. He adapted the general design for the ground, established the execution phases and developed in detail the plans for each of the buildings. The engineer arrived on the 28 June and a month later, on the 22 July, came Antonio de Ulloa, sent by the authorities on a long voyage around Europe, the first stop being Cartagena to help fix the plans along with the already famous engineer, Feringán. Together with Antonio de Ulloa, Feringán modified Autrán's plans to arrive at the definitive design plan for the building of the arsenal and naval base in September 1749, after three years of study and debate.

H.M. Fernando VI then decided to complete the plans for the arsenal by adding dry docks, the first in the Mediterranean. He sent the sea captain, D. Jorge Juan y Santacilia, to meet with Feringán so that they could agree upon the appropriate modifications to the design, thus giving rise to the plan which was followed in the building of the arsenal that we can still see today **(fig. 9)**.

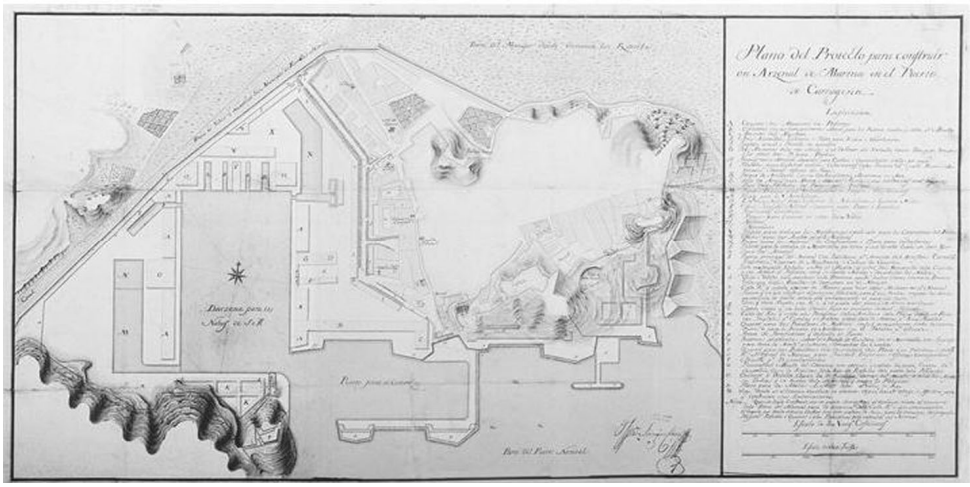

Figure 9. Design plan for the building of a Navy arsenal in the port of Cartagena (Sebastián Feringán Cortés 1751, AGS, M. P. D., XXI-11)

On the 2 December 1749 Feringán sent the Marquess de la Ensenada the plans for the construction of the piers surrounding the arsenal's dockyard, accompanied by a letter that provides some interesting information on the project:

> I am sending you the plan and profile of the design I have devised for the building of the piers which are to surround the dock, adapted to that approved in the general design project, the construction of which will be 540 yards in length on the East, North and West sides and in part of the South… 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 below sea level must be reached in order to dig. Once this is done, we can say that the arsenal is finished, as the buildings do not pose any great difficulty, and all can be worked on and completed at the same time. It is a challenging project due to the sea and its tributaries and once started, must be continued without stopping, because if the water cannot be kept clear, this could cause an obstacle in the work […].
>
> (AGS, Marina, leg. 377; 2 December 1749)

We shall return to analyse how the foundations of the piers of the docks were laid, for, as Feringán says, it is the most extraordinary part of the underwater construction of this arsenal. While the

solution given in Figure 9 is the one that was eventually adopted for the construction of the arsenal piers, it was the outcome of an intellectual process and of a progressive knowledge of the terrain acquired over time. A brief look at earlier alternatives will be informative.

In 1731 Alejandro de Rez proposed building a new stone platform, rejecting the earlier suggestion to make it from wood and giving it a depth of 12 feet down to the underwater foundations **(fig. 10)**

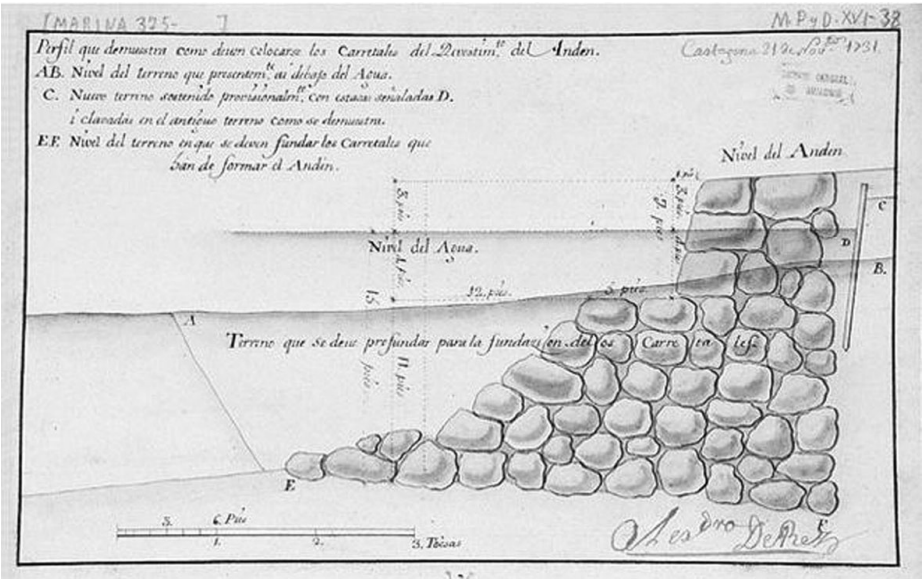

Figure 10. Cross-section showing how the exterior building blocks of the platform should be placed (Alejandro de Rez 1731, AGS, M. P. D., XVI-38)

Upon the death of Rez in 1732, Feringán took over, but not without opposition as the following comment shows:

> Sebastián Feringán replaced him, a man of whom I do not dispute the knowledge, because I consider him to be highly skilled, what I do dispute is the practice of working in water and using piles, something acquired through experience, which he cannot have since this is the first job on which it has been used; and this being a job of considerable dimensions, it seems that the most experienced expert should be sought at any price for the work to be perfected […].
>
> (AGS, Marina, leg. 379, 14 August 1737)

We have found a selection of detailed plans by Sebastián Feringán from the 1730s that provide valuable information on how the solution was arrived at. The principal changes proposed are summed up below **(fig. 11)**:

Changes made to earlier plans:

- The depth at which the foundations are laid underwater was increased to 20 feet.
- The depth of the artificial dock dug out in front of the platform was increased.
- In the cross-section of the pier the difference between the elements of which it is made up, can be clearly seen: the foundations are made of four rows of stone building blocks and the elevation, as if it were a wall, with a exterior layer of building blocks which protect the building from the beating of the waves, which are filled with masonry.
- The width of the platform up to the facade of the warehouses and buildings built upon it must be 24 feet, so guaranteeing that shifts in the ground will not damage them.

Method for carrying out the work:

- The foundations are laid in a fragmented manner using caissons that are supported using wooden boards holding the earth from the excavation.
- The construction of wells in front of the excavations, in which to place the pumps which will pump out the water while the work is in progress.

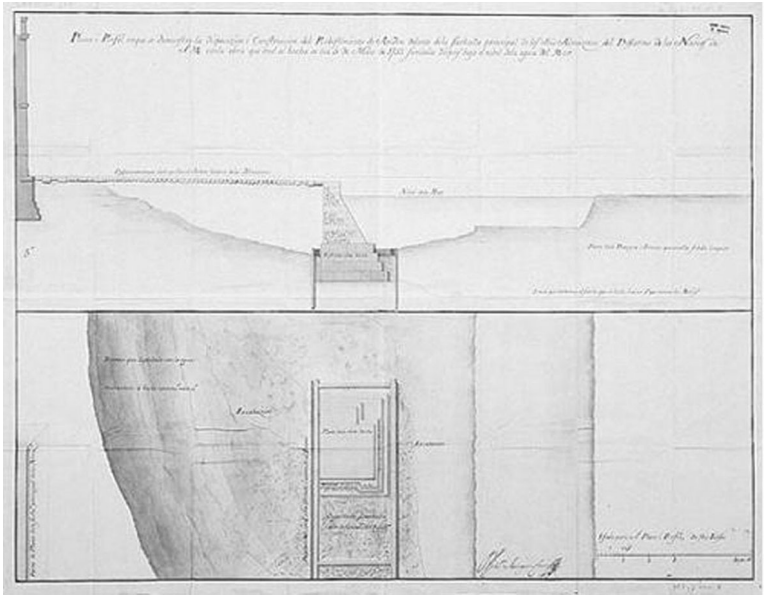

Figure 11. Plan and cross-section showing the outside appearance and construction of the platform in front of the main facade with the work completed on 5 May 1733 (Feringán 1733, AGS, M. P. D., XXIV-8)

Due to his mistrust in the professional expertise of Ferigán in underwater construction, minister Patiño asked the opinion of engineer Montaigú de la Perille, who, several months later, sent plans

for the construction of the platform and the precautions that were to be taken during construction **(fig. 12)**. In these documents several new aspects can be seen. The depth of the foundations below sea level is increased to 29 feet, the depth of the artificial dock excavated in front of the platform is increased to 28 feet, so that ships of a greater volume could have access, and most important of all, the decrease in the width of the platform to 12 yards. This change meant that the entire construction system for the foundations had to be reconsidered. Also that a solution had to be found to reuse that which had been constructed up to that point with a width of 24 yards.

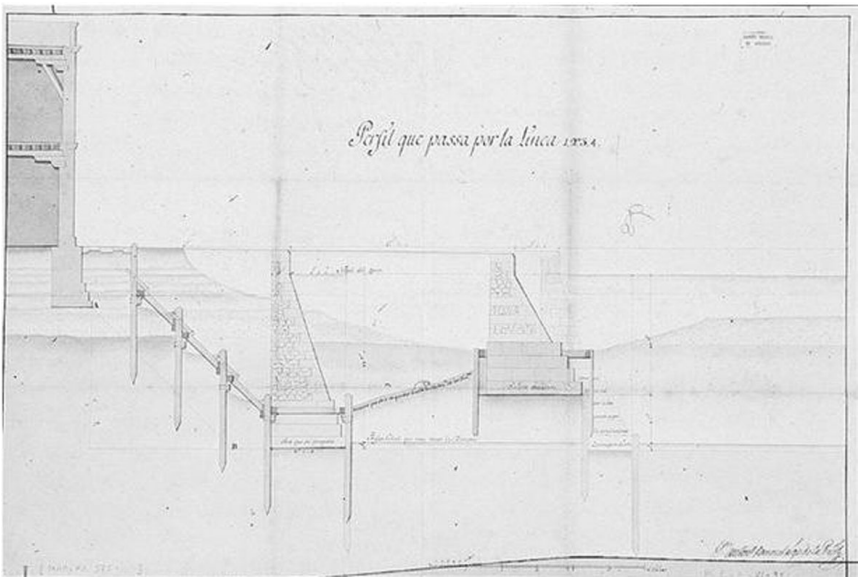

Figure 12. Cross-section of the plan indicating the way the platform was to be built in front of the Navy warehouses in Cartagena (Montaigú de la Perille 1733, AGS, M. P. D., VI-95)

Along with these plans Montaigú wrote the following report:

> […] even though I have proposed 12 yards in width, this does not mean that the construction shall be less robust and more dangerous […] that if it is built to a width of 24 yards as at the start, then it is true that having put in four rows of stakes which mark out the plan and cross section, any water passing through will not have as much effect due to the protection of the foundations of said warehouses […]. The stakes are well driven in, ensuring that they are strong and able to resist an even greater weight from the earth that they must hold, and they are not affected by any pressure from the warehouses as this pressure only corresponds to the marked hypotenuse (on the cross-section) AB of the right-angled triangle which has two sides equal to the height at which the force ends […]".
>
> (AGS, Marina, leg. 375, 22 July 1733)

The solution eventually implemented by Feringán for the construction of the piers in the 1740s returned to the depth of the foundations at 30 feet, as originally proposed, but with an intermediate width of 16 yards for the platform **(fig. 13)**. Moreover, in his sketches Feringán redesigned the pump system that was to pump out the water day and night during the building operations.

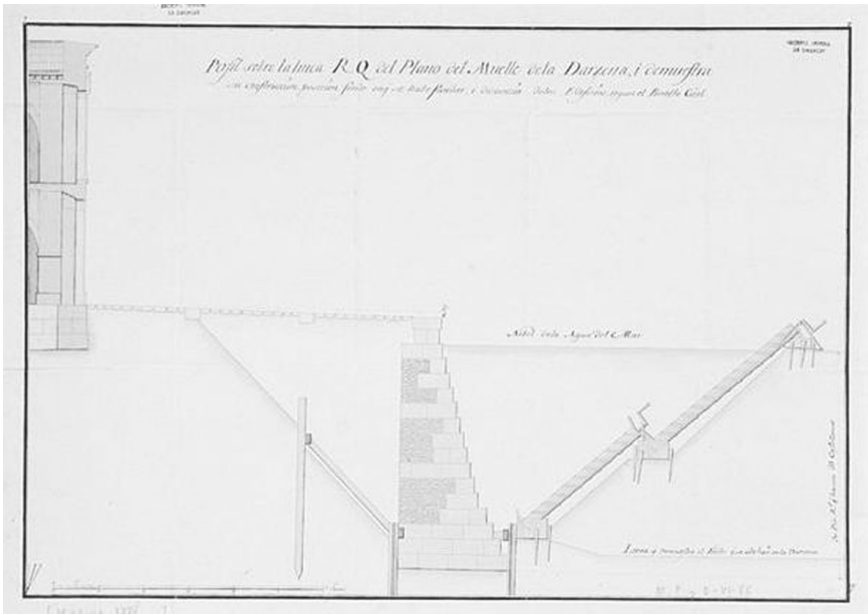

Figure 13. Cross section along the line RQ of the plan of the pier in the dock showing its construction, position, depth at which it is to be set and the distance between the buildings (Feringán 1749. AGS, M. P. D., VI-86)

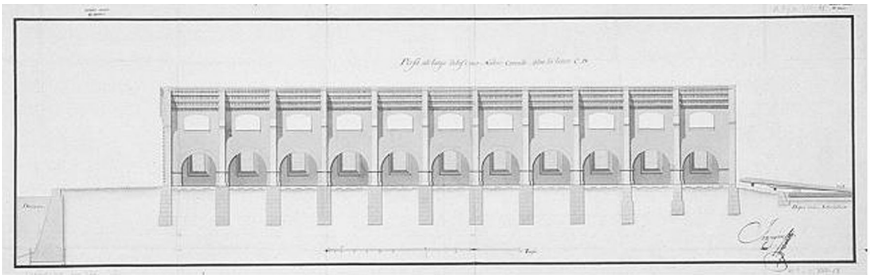

Figure 14. Cross-section indicating the foundations are to be built on the west platform (Feringán 1750, AGS, M. P. D., XVII-18)

The proposals that were made for the laying of the foundations of the royal arsenal in Cartagena **(figs. 14 and 15)** show the definitive solution to have been adapted to each of the types of ground that could be found on either side of the perimeter of the dry dock. This was less resistant on the

east, north and south platforms due to the presence of mud and it was decided that the foundations should be laid using piles. However, on the east platform where rocky ground provided a solid base it was decided that the work should be carried out using a foundation of stone building blocks as suggested by Feringán in his last proposal.

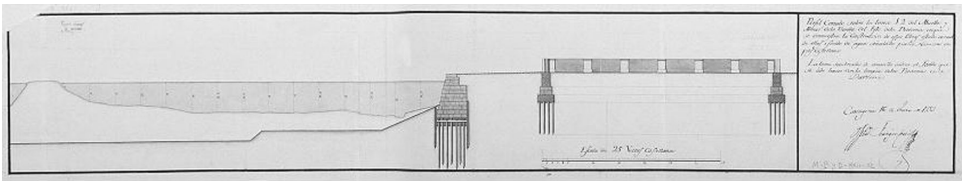

Figure 15. Cross-section indicating the foundations are to be built on the east platform
(Feringán 1753, AGS, M. P. D., XVII-12)

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