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Introduction

Art historians George Roseborough Collins (1917-1993) [1] and Turpin Chambers Bannister (1904-982) [2] made known in the *Journal of the Society of Architectural Historians* (1968), the unique typology of construction with *bóvedas tabicadas* and brought them closer to the international debate of architectural history. They treated with special emphasis Rafael Guastavino Moreno (1842-1908), a key figure in understanding the transfer of the cohesive construction of European tradition to the United States of America, produced after the Chicago fire (1871).

In the *Essay on the Theory and History of Cohesive Construction* applied especially to the timbrel vault (1892) [3], he defined cohesive construction as one that is carried out by assimilating different materials through the use of mortars, compared to what he calls mechanical construction, which works by gravity and demonstrated knowledge that the construction system was used in the Corona de Aragon region [4], on the Iberian Peninsula, since the 14th century [5].

The Duke of Belle-Isle and the Count of Espié had known in their crusades of the War of Succession (1701-1715) *la voûte à la Roussillon.* These tile vaults were well received throughout Europe as well as in Spain (where they were well-known since the 14th Century) thanks to the dissemination of the texts of the Count of Espié (1754) and Pierre Patte (1777). We determine what use the tile vaults had from the point of view of military construction, favoured by their supposed mechanical qualities, and what the repercussion was among Spanish military engineers in the 18th Century, on the base that the location of the projects carried out through this technique by military engineers in Eastern Spain coincides with the places where a specialized workforce already existed, and that people in those places already knew such construction technique. In Spain, the work of the Count of Espié had more influence among the architects of the Royal Academy of San Fernando, than among the Military Engineers of the Academy of Mathematics of Barcelona.

The study is limited to the interpretation of the graphic representations of the projects of the engineers belonging to the Collective Catalogue of the Collections of Maps, Plans and Drawings of the State Archives of the Ministry of Culture, and the Collection of Maps, Plans and Drawings of the General Archive of Simancas, as well as the map library of the Ministry of Defence together with the consultation of the General Archive of Segovia, the General Military Archive of Madrid and the Naval Museum of Madrid.

The Rediscovery of the voûte à la Roussillon or volta de maó

Félix François, Count of Espié, had presented a Project of Military School (1751) to Louis XV of France (1710-1774), later published as *Réflexions du Comte sur l'établissement de l'École militaire* (1756) [6]. In this parenthesis, he published *the Manière de rendre toutes sortes d'édifices incombustibles* (1754), which he said, provided instruction for the use of tile vaults to safeguard strongholds from enemy the fire [7] (Fig. 1a).

The Spanish translation, *Modo de hacer incombustibles los edificios* (1776), was made by Joaquín de Sotomayor Cisneros y Sarmiento (f. 1776) [8]. Despite this, the tile system was questioned by the Académie Royale d'Architecture (1747) owing to the demand of the Capuchin Fathers for the construction of the Montauban convent, even though they recognized that the technique had already been introduced by this Order in the convent of Castelnaudary in Languedoc [9]. The discussion of monolithism and the thrust of tile vaults between the Count of Espié and the answer of Ventura Rodríguez (1717-1785) in the *Censura de la trabajo de Sotomayor* (1776) has been widely disseminated [10] [11]. The fire behavior of these vaults was to be one of the arguments in favor of the so-called cohesive construction by Rafael Guastavino Moreno (1842-1908) in the *Essay on the Theory and History of Cohesive Construction* applied especially to the timbrel vault (1892) [12].

This last defined it as the one that is carried out by the assimilation of different materials, compared to what he calls mechanical construction that works by gravity, usually used by military engineers [13] (Fig. 1c).



Figure 1: Tile vaults; a) Count of Espié (1765); b) Pierre Patte (1777), c) Rafael Guastavino (1892)

Félix François, Count of Espié, and the Academia de Bellas Artes de San Fernando

Diego de Villanueva (1713-1774) was the Director of the Architecture Department at the San Fernando Academy of Fine Arts (1756) and spread his doctrine in the *Colección de diferentes papeles críticos sobre todas las partes de la Arquitectura* (1766) [14]. In his Letter 1, he cites as reference authors the Abbè Marc-Antoine Laugier, (1713-1769) and P. Lauguier (1745). In his *Essai sur l'architecture* [15], a work also structured as letters, he addresses similar topics. He also cites the *Mémoires critiques de l'architecture* (1702) by Michel de Frémin (f. 1686), the *Mecure de France* (1747) and the Letter VII to Amadée Francois Frezier.

In the text of the Letter No.VI "On the art of manufacturing; and fraud against the Workers", similar to Abbè Laugier's one (1745), he quotes the Count of Espié. His work specifies that the *Comble Briqueté* were buildings roofed without the use of wood or iron, only with flat bricks, laid with plaster, lime and sand mortar and built on *Voutes Plates*. As a military man, he referred to this type of construction to safeguard strongholds, warehouses and arsenals from fire. It also concluded that this type of construction did not produce thrusts since the partitions of the tabs performed the function of bracing, causing a monolithic structural operation. In the translation of the work of the Count of Espié by Joaquín de Sotomayor (1776), additions were made to what was known in the *Observations sur l'Architecture* (1765) by Marc-Antoine Laugier (1713-1769). In the censorship of the work, Ventura Rodríguez (1717-1785) addressed the thrust of the vaults, contradicting Espié whose theory and effect of the thrusts had already been described by Fray Lorenzo de San Nicolas (1593-1679).

Illustrated knowledge of the military engineers of the 18th century

King Felipe V (1683-1746) was to appoint Jorge Prosper Verboom (1665-1744) General Engineer and Mateo Calabro (1680-1748) director of the Academy of Mathematics of Barcelona (1720-1738), a position that was held later by Pedro de Lucuze and Ponce (1692-1779) between (1738-1779). In the curricula of the Academy under Calabro (1724), Verboom (1739) and Pedro de Lucuze (1738) (16) the texts were *The first six books of the geometry of Euclides* (1576) by Rodrigo Zamorano (1542-1620), the *Nouveaux Éléments de géométrie* (1667) by Antoine Arnauld (1612-1694), *La geometrie des lignes et des surfaces rectilignes et circulaires* (1712) by Jean-Pierre de Crousaz (1663-1750), *Mathemático* (1707-1715) by Tomás Vicente Tosca (1651-1723), *le Nouveau cours de Mathématiques* (1725) by Bernard Forest de Belidor (1698-1761) and the *Traité d'Architecture* (1714) by Sébastien Le Clerc (1637-1714). The Royal Military Academy of Mathematics of Barcelona printed some texts on its own initiative. Thus, the works of John Müller (1699-1784), *A treatise containing the elementary part of fortification*, *regular and irregular* (1755), of Miguel Sánchez Taramas (1733-1799) published as *The Principles of Fortification* (1772) and Pedro de Lucuze and the Military Notions or Supplement to the Principles of Fortification (1772) and Pedro de Lucuze and the Military Notions or Supplement to the Principles of the Academy on the Treaty VIII of Civil Architecture dictated by Pedro de Lucuze in the period (1739-1779)

Among the architecture books, there were the Vitruvio editions: Sabatini had Cesare Cesariano's edition (1521) and Claude Perrault's called *Les dix livres d*⁻*architecture de Vitruve*, (1673) and together with Verboom and Hermosilla he also had, from the translation of José de Castañeda (1766), published as *Compendio de los diez libros de Arquitectura de Vitruvio* (1761). We know that Cermeño owned an edition of Serlio and Verboom of the *Extraordinario Libro di Architettura* (1551). Also, Sabatini owned an edition of the *I quattro libri de l''Architettura* (1547) and of *Tutte l'opere d'architettura* (1584), completing his library *I quattro libri de l''Architettura* (1570) by Palladio, Le due regole della prospettiva pratica (1583) by Vignola and Dell'Idea dell'Architettura Universale (1615) by Scamozzi.

As for French treaties, Verboom had the *Cours d'architecture qui comprend les ordres de Vignole* (1691) by Agustín-Charles d'Avilier, in the Sabatini library were *les Ordonnance des cinq espèces de colonnes selon la méthode des Anciens* (1683) by Perrault, *La théorie et la pratique de la coupe des pierres* (1737-1739) by Frezier, *Mémoires sur les objets les plus importants de l'architecture* (1769) by Patte and the *Cours d'architecture* (1771-1777) by Blondel and Patte

Tile vaults of the military engineers of the 18th century

This construction system of tile vaults was executed through the combined action of layers of thin brick tiles. The first of these ceramic sheets that forms the soffit was made with plaster paste, while the others could also be made with lime mortar. The slats were arranged in a plank and tangent to the guideline of the vault and the upper ones were placed in a joint and in different directions. The main characteristic of this type of construction was the use of plaster as a binder. This material, kneaded with water, involves rehydration and reacts with an increase in temperature, resistance and initial

volume in a short time. Its use was reserved for the covering of warehouses, domes, construction of floor support and stairs.

We can compare the difference between bricks and masonry vaulted construction in the two designs for the dome of the church of the citadel of Barcelona. A first project (c.1717), by an unknown author [MPD, 02, 047] [1], was made with stonework (Fig. 2a), while the later in essay (1724) by Francisco de la Pierre (f. 1690-1760) [MPD, 16, 024], was made with a tile vault (Fig. 2b). In the sections, it is possible to observe the great difference in thickness and, therefore, the great difference between the masses and counteracting thrusts.



Figure 2: Citadel Barcelona; a) Anonymous, masonry dome (c.1717); b) F. de la Pierre, tile vault (1724).

The difference in the construction systems can be verified in the two projects drawn up by Carlos Berenguer (1698-1756) for the construction of a sentry box in Alicante: "Plano, y Perfil de una Garita que se propone executar inmediato al Almazén de Polvora para su custodia" (1751) [MPD, 06, 167] and "Perfil, y Vista de Una de las garitas proyectadas de Piedra de sillería, para la Plaza de Alicante" (1752) [MPD, 06, 161].

Between the two, the different speed of execution is evident in the term "execute immediately" for the tile vault, compared to "ashlar stone". The latter is more resistant, but it presents a great difference in terms of the material availability and the execution period. These systems were also used for small vaulted constructions such as the guardhouse or the dome of a chapel. That was the case of the project for the Chapel on the Muelle de Levante in Malaga (1727) by Juan de la Feriére (f. 1724-1737) [MPD, 29, 091] (Fig. 3a) and [MPD, 08, 197] (Fig. 3b).



Figure 3: Chapel in the Muelle de Málaga (1727), by Juan de la Feriére; a) [MPD, 29, 091]; b) [MPD, 08, 197]

Tile vaults in church buildings

Since the 17th century, there was a practice in civil architecture to use the tile vault to cover the naves in religious buildings. The system, subjected to its own weight and a maintenance overload, has less thrust and cracks than churches built with masonry. Above these vaults, the roof of the buildings presents different types of sloping or flat roofs.



Figure 4: Vaults under roof; a) Flat and sloping Barcelona [MPD, 08, 104]; b) El Ferrol gabled [MPD, 15, 017].

This is the case of the flat and inclined roof in the project for the end of the choir of the church of the Citadel of Barcelona (1718) by Alejandro de Rez (f. 1710-1729), [MPD, 08, 104], (Fig. 4a), it is also the case of the sloping gable roof of the new parish of San Julián in El Ferrol (1764) by Pedro Ignacio de Lizardi (f. 1760-1775), [MPD, 15, 017] (Fig. 4b).

Tile domes

Military architecture gathered the symbolism of the domes used in religious architecture and used them as elements of representation of hegemony within some military enclosures, as can be seen in different projects for the Barcelona arsenal. For example, in Jorge Próspero de Verboom's (1665-1744) Profile of the entire building cut on the BHI line of the horizontal plan of the Arsenal to be built in the citadel of Barcelona (1717), [MPD, 14, 003] (Fig. 5a), or later in the design (1730) by Andrés de los Cobos, (f. 1700-1737), [MPD, 18, 004] (Fig. 5.b) that also appears unsigned [MPD, 18, 005] as a duplicate required by the Ordinance of 1718.



Figure 5: Domes for Arsenal de Barcelona; a) Jorge Próspero de Verboom (1717) [MPD, 14, 003]; b) Andres de los Cobos (1718) [MPD, 18, 004]

Tile vaults in slabs

The types of forging in military buildings were very varied. Although the most widely used was the ceramic vault between wooden beams, there were projects with wooden floor slabs or edge brick vaults. We have evidence of the use of tile vaults in the Lonja Barracks in Barcelona (1741), [MPD, 18, 091] by Miguel Marín (f. 1718-174), with details of the specific section of the project [MPD, 18, 091]. A very particular case are the vaults of the "Plano, Perfil y Elevación del cuartel nuevo de Caballería, unido a la Real Academia de Matemáticas en la Plaza de Barcelona, capaz para un Escuadrón" (1759) by Pedro Martín Cermeño (1722-1792), [MPD, 10, 012] In this project, the main vaults are locked to the arches by means of tabs on their rear side. These elements, located symmetrically on the main vault, are built in the shape of a jumble, although they are somewhat sloping and also serve to support the flooring.

Tile vaults in stairs

One of the elements that has lasted and that has survived to our day is the tile staircase disseminated by Manuel Fornés Gurrea (1777-1856), in his *Observaciones sobre la práctica del arte de edificar*, [fol 19-22 (1841)] (44). The use of this system by unloading an arc curve allows great flexibility in setting out different runs of stairs. On the other hand, the rehydration of the gypsum mass causes crystallization to take place with a rapid hardening of the material, which allows a very fast execution owing to the shortage of auxiliary elements. This would be the case of the project of the Cut Profile in the LMN line of the Arsenal that has to be built in the Citadel of Barcelona (1717) by Jorge Prosper Verboom (1665-1744,) [MPD, 14, 002] (Fig. 6a).



Figure 6: Detail of vault stairs; a) Jorge Prosper Verboom (1717) [MPD, 14, 002]; b) Miguel Marín (1740) [MPD, 07, 128]

If the previous project started with a staircase with straight sections, we have also been able to analyze the design of a helical staircase designed by Miguel Marín (f. 1718-1742). Its first version under the title "*Perfil de la Linterna según la línea C. D. de los muelles proyectados en Barcelona, con sus baterías a la cabeza, cuerpos de guardia, almacenes de pólvora y cisternas*" (1740), [MPD, 07, 013] (Fig. 6b) was subsequently rectified as Elevation of the lantern with that of the elliptical battery according to the dotted line RS (1743), [MPD, 07, 128]. In both cases, a form, similar to that of the staircase initially projected, was maintained.

Vault thrusts

The revision of the theory of the Count of Espié (1765) on the monolithism and the thrusts of the tile vaults was already answered by Juan de Herrera (1776), but we have previous evidence in which there is proof of knowledge from the Spanish engineers on the abutment of these vaults. This is the case of the Orihuela Barracks project (1747) by Pedro Torbe, (f. 1743-1772) in a first section of August 3rd, carried out by the access to the barracks: "*Perfil cortado según la línea A.BB, y C. del Cuartel de Orihuela*" (1747), [MPD, 27, 062] (Fig. 7).

Subsequently, there was a modification of the section, dated October 21: "*Perfil de una de las Alas del Quartel de caballeria, el que representa la nueba disposicion de su cubierta, y juntamente la Abitacion que quedara para los soldados, y Omenages a la Tropa"* (1747), [MPD, 67, 080]. In the explanation of this modification was specified: "8, Encased to receive the roof, and together they serve to abut the barrel of the *Bobeda* of other *Attics*. In the first place, a more slender and steeper section of the roof can be seen in the modification, and secondly, the definition of the cladding with the specific function of operating as the tabs to tie down this type of vaults.



Figure 7: Orihuela Barracks, Pedro Torbe (1747). Push vaults, [MPD, 27, 062], [MPD, 67, 080].

Fireproof vault

A knowledge of the fireproofing properties of tile vaults is manifested in the texts of the Count of Espié (1765) of Sotomayor (1776) or of Patte (1777), and is quoted verbatim in that of the "*Proyecto del Cuartel de la Puerta de los Pozos dirigido a Sabatini*" (1794): Plan and profile of a new way to build an Infantry Barracks in accordance with the modern and advantageous footing of the method that has been followed up to now, [AGMS [2]. Signature: 3rd / 3rd / File 577]. The barracks were located at the door of the snow wells of Madrid, and refers to Francisco de Sabatini as Director and General Commander in ownership of roads, bridges, buildings of civil architecture and irrigation and navigation channels, and Inspector General of the Academies and Fortifications branches (1791-1797) and also as a designer of some of the Gates of Madrid and as a connoisseur of Patte's text (1777) in his library. The project legend indicates the advantages of the new metric and constructive system:

Non-defensive construction of the military engineers of the 18th century

In the formative treatise of engineers, the construction of non-defensive elements was addressed. This was indicated by the translation by Miguel Sánchez Taramas (1733-1799) of the title *A treatise containing the elementary part of fortification, regular and irregular* (1755) by John Müller by *Tratado de fortificación, ó Arte de construir los edificios militares, y civiles* (1769). This work dedicates Section XIX to powder magazines and Section XX to barracks, arsenals and hospitals. Regarding the barracks, it qualified those dedicated to the Cavalry Corps due to the specific need for the

Cinta Lluis-Teruel, Iñigo Ugalde-Blázquez, Josep Lluis i Ginovart and Zahra Hadji

construction of the stables with respect to the other weapons. Miguel Sánchez Taramas introduced some Additions for the Iberian readaptation of John Müller's treatise with its own constructive characteristics. For its part, *The Principles of Fortification* (1772) by Pedro de Lucuze, makes reference in its Chapter XIX to the Main Buildings which it defined as military buildings: the General Staff quarters, barracks, pavilions, hospitals, food stores and ammunition, church and cistern, considering them constructively as a simple type or as a bomb-proof type.

Quarters

In the additions of Miguel Sánchez Taramas (1733-1799) to the Tratado de fortificación, ó Arte de construir los edificios militares, y civiles (1769), reference is made in Plate No. 7 to the project of the Reus Cavalry Barracks by Juan Martín Cermeño (1700-1773) entitled "Plano ynferior del quartel y pavellones que se esta executando en la Villa de Reus capaz de 700 ynfantes, un esquadrón de cavalleria y los correspondientes oficiales, cuio proyecto se deve seguir igualmente en los de Valls y Villanueba de la Geltrú" (1751) [MPD, 20, 028]. Both the project and the text became a prototype to be followed in order to be reproduced as a typological model. Regarding tile construction, Miguel Sánchez Taramas said:

This is clearly manifested in the interior structure of the Building, the nature of its Vaults (which are partitions, and built by Arista), the arrangement of the Stairs, the magnitude and number of the Arches and Pillars of the Corridors, the formation of the Armor [fol-384-385 (1769)].

In this same year, Juan Martín Cermeño carried out the Project of a Quartel that requested the erection of the Villa of Villafranca de Panades, for two Cavalry Squadrons or a Ynfanteria Battalion with corresponding Pavilions for officers [MPD, 08, 136] (Fig. 8a). The section of the project is identical, although symmetrical, to that of the text of the Tratado de fortificación, ó Arte de construir los edificios militares, y civiles (1769) (Fig. 8.b). Consequently, it is a matter of systematizing a typological model both from the formal distribution of the building and from the building construction point of view through the use of ceramic masonry in walls, pillars, arches and tile vaults.



Fig. 8. a) Villafranca Penedés Barracks, Juan Martín Cermeño (1769) [MPD, 08, 136]; b) Reus Cavalry Barracks Section Fortification Treaty (1769)

The system was previously used by Nicolás Agustín Bodin y de Bellet (f. 1718-1753) for the construction of barracks, as is the case of the "*Planta y dos perfiles del cuartel de Alicante que se proyecta*" (1739) [MPD, 25, 095] and of the "*Plan, Profiles and elevations of a Quartel de Cavallería for abating 200 soldiers*" (1741) [MPD, 10, 092].

Stables

While the barracks for the accommodation of troops had to be housed near the bastions, the location of those for cavalry were governed by the usefulness of the horses and required particularly the supply of water for their hygiene and maintenance. Therefore, its location was relegated to this need. The layout of the stables was determined in two ways: one for the stables and the other for the circulation and maintenance of the horses. In cases where the stables had only one floor, they were covered by tile vaults, as shown in the projects by Pedro Torbe (f. 1743-1772 ""Plano inferior del Cuartel de Caballería que se está construyendo extramuros del Arrabal de la ciudad de Orihuela, Proyecto de aumento de Caballerizas"" (1747), [MPD, 27, 061] and "Plano del fuerte llamado San Carlos, situado en la Costa de Levante de la Ciudad de Málaga" (1796) [MPD , 65, 029] by Fernando Pirez (f. 1788-1801).

Grocery stores

Pedro de Lucuze said that warehouses had to be built in dry places, distributed and not very far from the barracks. This is particularly so of the project for a salt warehouse in Zaragoza which, due to the special conditions of the condiments and the need to be housed in a place with low humidity, was built by use of a tile system. The project was by the engineer Narciso Brer y Miró (f.1769) and was entitled "Plano y Perfil del Almacen de Sal que se propone en el Lugar de Remolinos del Reyno de Aragon" (1769) [MPD, 68, 097].

Main buildings

In Pedro de Lucuze's instructions, the existence of representative buildings located in the main square of the arsenal or the fortified squares is referred to. As examples of tile constructions in these forms of construction we have the project by Juan Caballero (1713-1791) for the Cadiz Customs Office (1769), [MPD, 14, 025] (Fig. 9.a) or the Sala de Armas del Ferrol (1769) [MPD, 51, 019] by Julián Sánchez Bort (1725-1781). (Fig. 9b).



Fig. 9 a) Cadiz Customs Juan Caballero (1769) [MPD, 14, 025]; b) House of Arms Ferrol Julián Sánchez Bort (1769) [MPD, 51, 019].

Hospitals

John Müller sized the Hospitals according to the garrison of the square, using the criterion of one bed for every hundred soldiers. For his part, Pedro de Lucuze advocated his situation within the Plaza Fuerte, being secluded and close to a place with a water supply. For this type of building with a structure similar to that of the barracks, is an account of the project for the Hospital de Algeciras (1745) [MPD, 27, 059] by Loren-zo de Solís (1693-1761).

Churches

The churches of the fortified enclosure, according to John Müller and Pedro de Lucuze, must occupy the main site of the square, near the Governor's house. The chapels were also projected as an auxiliary element within hospitals, for spiritual assistance to the sick or wounded. Among these projects is the "Planta, Elevación y Corte interior de la Obra más proporcionada que puede hacerse en la Iglesia de San Bernardo Extramuros de Toledo" (1748), [MPD, 09, 038] by José Hernández Sierra (c.1705-1782) as well as Interior representation of the parish church projected for the new city of Ferrol; Main façade for the same church (1763) by Julián Sánchez Bort (1725-1781), [MPD, 05, 053] and other projects for arsenals such as Ferrol (1764) [MPD, 05, 055 .] by Pedro Ignacio de Lizardi (f. 1760-1775) (Fig. 10a) and that of La Carraca de Cádiz and its church (1785) [MNM, Sig. MN-P-2E-36] by Francisco Autrán de la Torre (1736-1792) (Fig. 10b).



Fig. 10. Church for Arsenals a) Ferrol, Pedro Ignacio de Lizardi (1764) [MPD, 05, 055.]; b) Cádiz, Francisco Autrán de la Torre (1785) [MNM, Sig. MN-P-2E-36]

Conclusion

The Corps of Military Engineers used tile vaults as a local construction system of skilled labor used in the Iberian Peninsula since the 14th century for the construction of domes, vaults and staircases. An example of this is the project for the Cuartel de Caballería de Orihuela (1747), [MPD, 27, 061] which preceded the publication of the Count of Espié (1754) and was contemporary with the Castle of Bizy (1740). Miguel Sánchez Taramas (1769) recommended tile

construction for the Barracks of Reus (1751), noting that this system had already been used by Nicolás Agustín Bodin and de Bellet in the barracks of Alicante (1739) [MPD, 25, 095] and Orihuela (1741) [MPD, 10, 092] `

The tile construction was used in the Plan of the Citadel of Barcelona, developed by Jorge Prospero Verboom. He used it himself in the dome of the Arsenal (1717), [MPD, 14, 003] (Fig. 10a) while Andrés de los Cobos [MPD, 18, 004] (Fig. 10b) and Francisco de la Pierre (f. 1690-1760) [MPD, 16, 024] (Fig. 6b) also used it at the same time. His projects preceded the Royal Ordinance of 1718 and the teaching at the Barcelona Academy of Mathematics (1720). Construction with tile vaults was common in civil construction, throughout the Spanish Levante where most of these projects are located. Therefore, there was a rapid assimilation, from the beginning of the creation of the Corps of Military Engineers, of the use of this construction system that had been used in this territory for more than three centuries.

Abbrevations

[1] MPD: Mapas, Planos y Dibujos del Archivo General de Simancas.

- [2] AGMS: Archivo General Militar de Segovia
- [3] MNM: Museo Naval de Madrid

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