Ports Design and Construction Machinery Through 19th Century Atlases

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Abstract. During 19th century, ports and harbours design and construction techniques experienced an exponential growth in the Western countries. The new scientific paradigm brought deep knowledge about wave mechanics, and at the same time the steam technology deployed new machinery to address some of the construction issues troubling European engineers for decades. This paper shows some examples of the new machines and mechanisms developed in 19th century Europe for ports design and construction, with special interest in the *École nationale des ponts et chaussées* of Paris research. The graphic definition of such machines through engineering atlas volumes is also addressed.

Keywords: Ports design · Construction methods · History of construction · 19th century machines

1 Introduction

For many centuries, port and harbour construction techniques evolved very slowly. Some artificial harbours built during the Ancient Age were great examples of engineering quality techniques, even showing great size achievements – the civil and military ports of Cartago being extraordinary examples of both [1]. Nevertheless, during 19th century the construction techniques evolved much more rapidly than in previous times. The reasons for such a quick growth are diverse but interrelated.

First of all, the scientific corpus of mathematics and physics –and specially wave mechanics—had grown considerably. The works of Christiaan Huygens (1629–1695), Isaac Newton (1642–1727), Gottfried Wilhelm von Leibniz (1646–1716), Daniel Bernoulli (1700–1782) and Leonhard Paul Euler (1707–1783), among many others, became more accessible and familiar in many academic settings. At the middle of the 18th century, the “great schools” of engineering were founded in France, creating a model that was imitated in some other countries of Europe for many years. The *École royale des ponts et chaussées* was founded in 1747, and started researching about ports and harbour construction, as well as many other civil engineering endeavours [2]. These schools syllabuses brought to engineering the latest knowledge about mathematics and physics. In 19th century England, this trend was heavily supported by Osborne Reynolds (1842–1912) [3], who studied mathematics in Cambridge before becoming professor of engineering.

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A second reason is the birth of new engineering materials, such as modern hydraulic cements and steel. At the beginning of 19th century, Louis Vicat (1786–1861) and Egor Cheliev (1771–1839) had some success developing some modern hydraulic cement recipes in France and Russia, respectively [4, 5]. In 1822, James Frost (1780–1840) obtained a patent for his *Portland cement* or "British cement", as he would call it [6]. In 1855, sir Henry Bessemer (1813–1898) started the modern era of steelmaking with his industrial method to create steel from pig iron [7]. The new era of construction materials had started.

But the third reason is far from being the lesser of them –the steam revolution and the mechanical improvements that were brought to engineering. Traction and power became available everywhere through many mechanical advances, and railroads starting arriving to every corner of Europe, improving accessibility to these new mechanical inventions.

Some of the new machines were used for new scientific measurements related to wave mechanics and weather behaviour data collection. Others were needed for the new construction techniques, improved harbour operations or railroad integration in European ports. The objective of this paper is to acknowledge some of these machines, describing their operations and graphic representation through engineering atlases used in the *École des ponts et chaussées* of Paris. A descriptive methodology will be used, and the physic definition of the machine will be followed by a full description of uses, construction methods or other operations related to each of these mechanisms.

2 Description of the Machines and Their Graphic Representation Through Atlas Volumes

At the end of the 19th century, Médéric-Clement Lechalas (1820–1904) – general inspector of France Civil Engineering Corps- founded an editorial collection of engineering treaties, by the name of *Encyclopédie des Travaux Publics.* He was awarded the title of Officer of the Legion of Honour of France, and the gold medal of the International Exposition of Paris (1889) for exceling doing the coordination of these publications, as well as due to his presentations during the exposition and career.

As these works exemplary show the state of the art by the end of the 19th century engineering, they will be referred henceforth. Most of these books were comprised of some text volumes with descriptions and explanations for the students of engineering, as well as an atlas volume for graphic definition of machines and work procedures. The most important of the ports and harbours construction manuals were *Ports Maritimes* and *Travaux Maritimes, Phénomènes Marins, Accès des Ports,* written by professor F. Laroche, and edited from 1891 to 1893 by *Baudry et Compagnie.*

2.1 Machines to Measure Wave Physic Characteristics and Weather Extreme Conditions

Design characteristics for ports should be measured in extreme weather conditions. Stability and durability as well as finesse are required in such measure machines. In France, most of the extreme winds have a west or southwest origin (facing east) [8]. By the end of 19^{th} century, the Robinson anemometer design was rather frequently used (Fig. 1). Wind pressure was usually calculated from average speeds registered for ten or more minutes, although some peak values could be obtained considering just extreme gusts lasting a few seconds. This machine could register pressures of 275 kp/sq mtr[1] consistently, and even 678 kp/sq mtr during an isolated event, registered in 1877, January the 30^{th} [8]. In the atlas volume, the machine is determined by elevations, plan and perspective figures, shown below [9].

Other important values needed for ports design are related to the geometrical shape of the incoming waves during extreme weather conditions. Wave significant height and wave length are especially important to be determined, and both are related to the geometry of the incoming waves. Admiral F. E. Páris (1806–1893) invented a device to record the shape of waves going through his machine. It was based in a very long wooden pole, immersed vertically in the sea, remaining substantially immobile. A wooden plate of annular shape was then attached to the extreme of the pole, connecting the upper end with a suitably stretched elastic rubber thread, hence attached to instruments that registered the vertical movement of the pole. The atlas depicts a full elevation of the machine, as well as some details of the mechanisms making functional the whole system (Fig. 2).

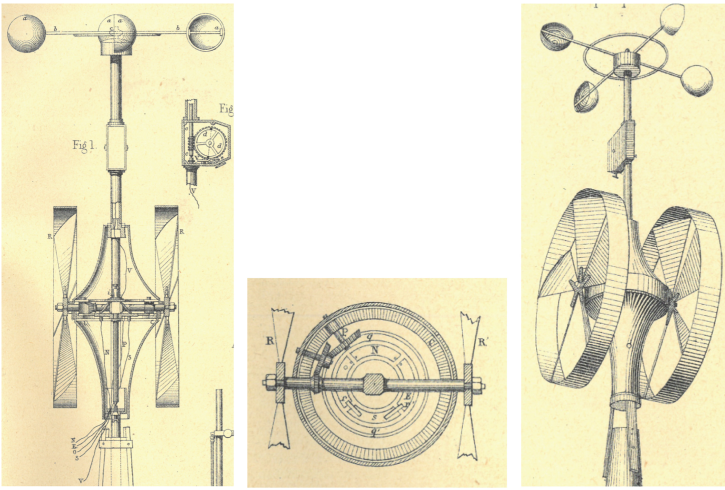

Fig. 1. Elevations, plan and perspective of the Robinson anemometer [9]

Another ingenious machine was created in 1842 by M. Aimé in Algiers harbour to recognize the depth under a vessel by the degree of agitation caused by the waves. It had to be installed in a well sized ship floating in a place where we could register water

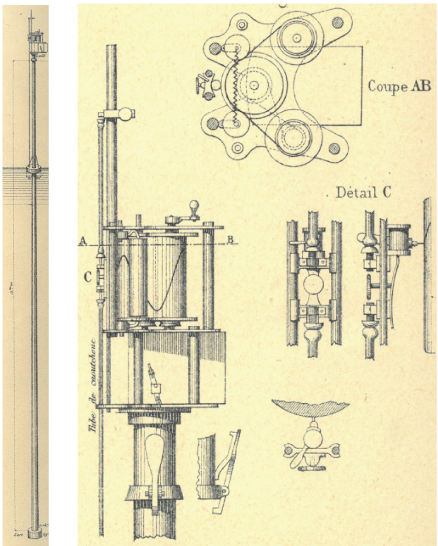

Fig. 2. Elevation and details of the admiral Páris machine [9]

agitation levels. A conic shaped piece, a little lighter than water, should be attached by its top using a short wire to a horizontal plate, usually covered in lead material. Iron weights were hanging from the corners of the plate, according to the perspective shown in Fig. 3. As the agitation registered by inclination of the conic piece decreased, the depth under the ship was known to be greater. So the machine would alert of less deep

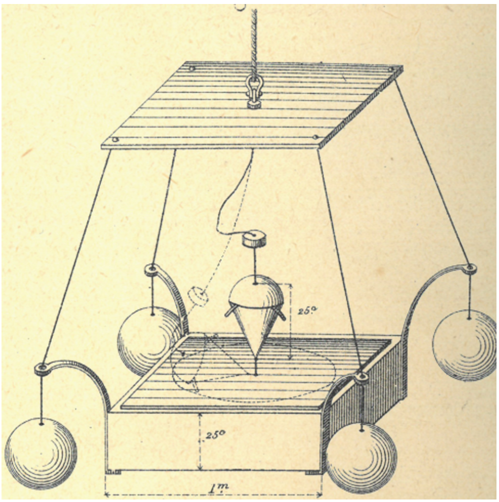

Fig. 3. Perspective of the Aimé machine [9]

areas showing greater inclinations of the conic shaped piece, according to tables created by Mr. Aimé.

2.2 Machines Used During Ports and Harbours Construction

The steam technology became extremely important to deploy traction power to the materials transportation, being probably the greatest of the 19th century innovation in pier construction engineering techniques. We will bring examples of transportation of different sizes of material used in pier building.

First, some techniques used sand or other granular materials to fill the territory where the pier was projected to be built. In these situations, little locomotives where used to transport loaded hopper buckets. The schematics of the construction methodology used for the construction of the Wicklow harbour in Ireland can be found as Fig. 4.

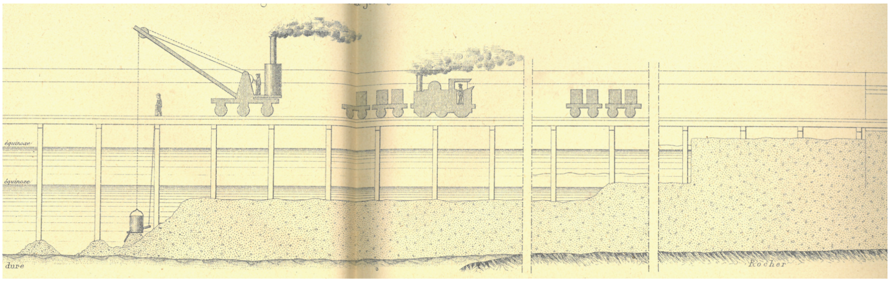

Fig. 4. Elevation of filling construction system using locomotives in Wicklow (Ireland) [9]

For bigger sized materials transportation, such as in the case of big stones, railroad-guided cranes were built. The design (Fig. 5) considered the bending moments balance of the whole transportation system, so the crane would not overturn by lack of equilibrium. The following machine was used during the construction of the port of Brest, in Brittany.

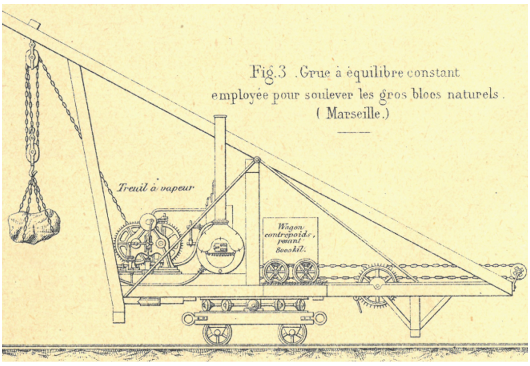

Fig. 5. Steam-powered railroad crane in Port of Brest [9]

The biggest sized blocks were transported using complete railroad rolling systems, including bigger sliding cranes (Fig. 6). The following machinery system was used to move and place into position the blocks needed for the piers of the Leixòes port, in Portugal. The graphic description in the atlas includes plan, elevations and several details of the wheeled transportation system, as well as the rotation mechanisms to allow the crane to change positions as needed. As the weight of the iron cast machinery was rather high, some of the details show the arch reinforcements needed for the whole structure to behave solidly and in equilibrium under all circumstances of load.

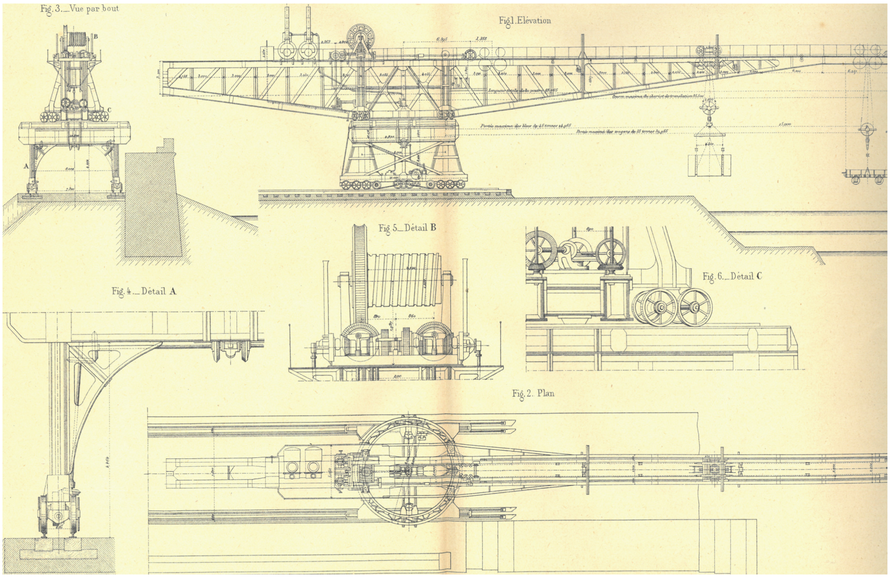

Fig. 6. Railroad big blocks transportation crane system in Leixòes (Portugal) [9]

2.3 Machines Used During Ports and Harbours Routine Operations

Although some of the more traditional machines, as load cranes, are described in these atlases, we will focus in the new machinery that modern materials and steam technologies created in 19th century.

Big breakwater structures were constructed to protect some harbours from extreme weather wave generation. Some of them were made not to last, just as an auxiliary structure to protect ports during construction works. Other breakwater structures stayed as permanent water surge protection. The following were used in the port of La Ciotat, next to Marseille (Fig. 7). Lattice-reinforced structures were connected by chains to avoid relative displacements, and were anchored to seabed in different points to assure the system as a whole was static. Both elevations were depicted in the atlases, as well as a plan distribution of the structures and anchor points (Fig. 8). Finally, a complete perspective of one of the breakwater structures was shown (Fig. 9). The complexity and weight of these structures were so high that they could only be made possible with an extensive use of steam-powered transportation systems.

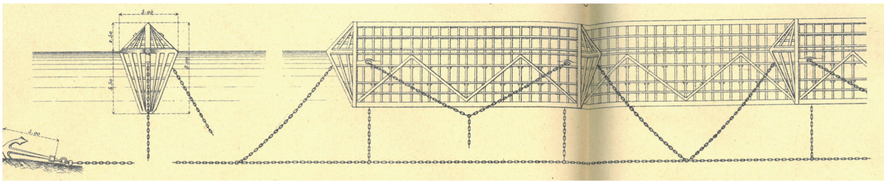

Fig. 7. Breakwater structure in La Ciotat (elevations) [9]

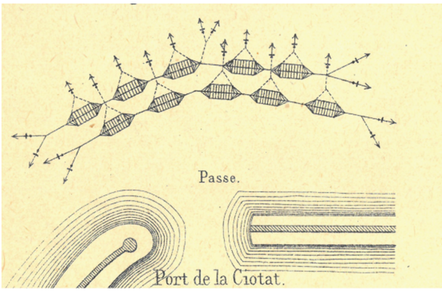

Fig. 8. Distribution of breakwater structures and anchor points in La Ciotat (plan) [9]

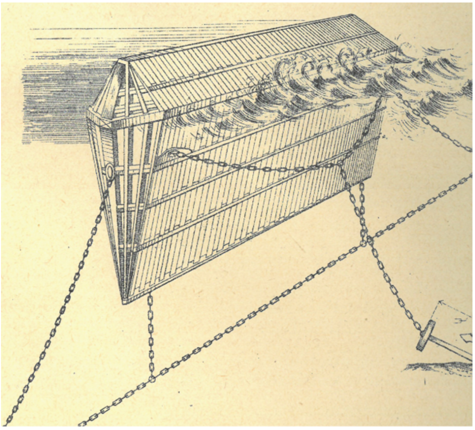

Fig. 9. Perspective view of breakwater structures in La Ciotat [9]

Probably, the floodgate systems were under their greatest changes during the 19th century. Some harbours could be improved, and some others fresh built as the floodgates measures were made much bigger in size. Bold designs were created in some English ports, Liverpool being one of the most important due to the paramount industrial activity taking place in the harbour areas. The following design was constructed in Liverpool

(Fig. 10), with a height of 11,51 m and a width of 30,48 m. Elevation, plan and three sections are shown.

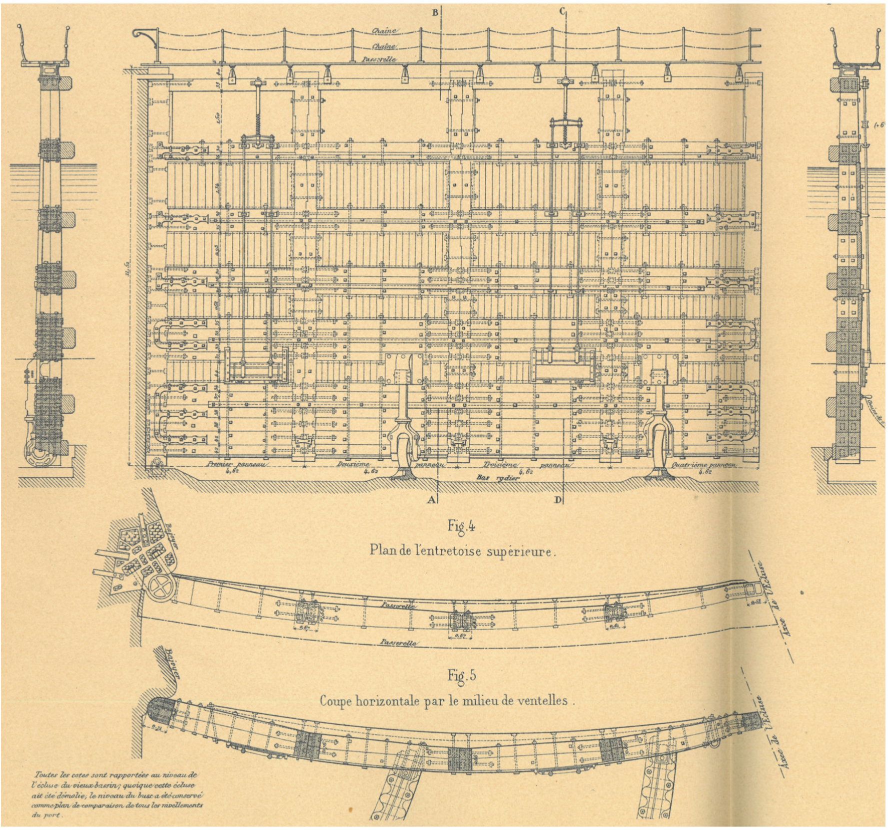

Fig. 10. Plan, main elevation and sections of Liverpool port floodgate [10]

The new steam traction systems allowed some of the bridges needed for road or railroad access to ports to be mobile. Henceforth, rotational and wheeled mobile bridge designs were built in the ports like Caen and Saint-Nazaire (France), respectively [11]. The possibility of making mobile bridges allowed for more bold designs, allowing also the displacement of access structures to allow navigation through floodgates or specially located port entrances.

The Caen rotational bridge is graphically defined by plan, main elevation and details of the rotation pivot structure, and was specially built over the Orne floodgate to allow navigation while vehicles access was not needed (Fig. 11).

The Saint-Nazaire wheeled mobile bridge could be slowly displaced using a steam boiler room installed in the vicinity. The main elevation and plan are referred (Fig. 12), as well as the steam industrial machinery attached to it (Fig. 13). Compression pumps chambers and boilers were included in the facilities.

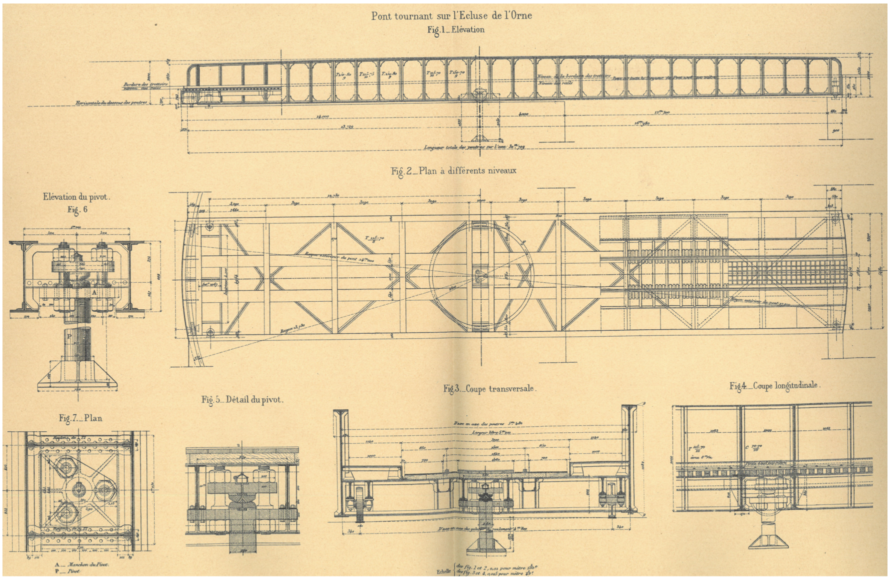

Fig. 11. Plan, main elevation and details of Caen rotational bridge [10]

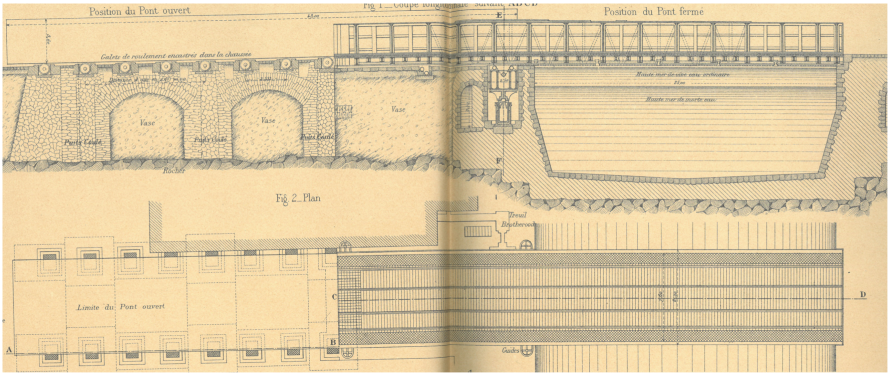

Fig. 12. Plan and main elevation of Saint-Nazaire mobile bridge [10]

As the technology became more usual, other ports installed these mobile bridge designs, as Le Havre in Normandy. Other interesting designs that can be found in the atlases are steam bells to be used as alarms in harbour installations [11], dry docks, railroad passenger and merchandise terminals, warehouses and coastal protections for beaches and military or strategic places of interest. Very advanced floodgate systems were installed in the Calais port, used by France and England as main commerce exchange international gate.

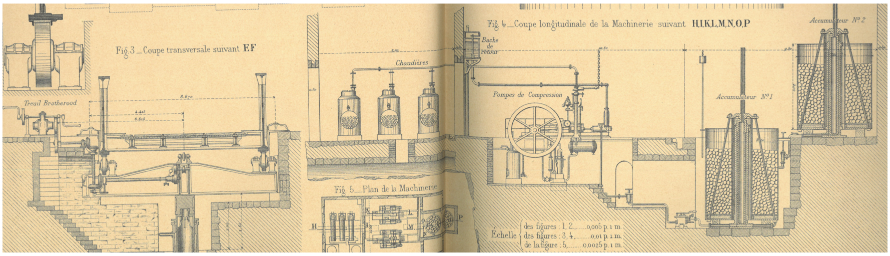

Fig. 13. Sections of the steam machinery for Saint-Nazaire mobile bridge, including boilers and compression pumps [10]

3 Conclusions

The new materials, construction techniques, steam-powered industrial designs and general scientific knowledge created an exponential growth for ports construction engineering techniques. New machines were designed to acquire environmental data, to improve construction methodologies or to allow better and easier ports routine operations. These designs were registered in engineering treaties used in the Great Schools of Engineering across the whole continent, including atlas volumes. The digitalization of these documents is essential to fully comprehend the importance of these facilities, and how to preserve the industrial remains of the steam era as part of the civil and industrial engineering history.

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