**Results and Conclusions**

The investigations as carried out allowed us to draw up the complex resource character of the wide-spread medicinal plant Rosa canina L.S.l. in the Karadag reservation. Its cenopopulations were found to differ from each other by quantity, age structure, vitality and productivity. It is advisable to store up the dog-rose fruit in cenopopulations of normal mature type, where intensively fruit-bearing middle-aged generative shrubs are prevalent, and also in normal aging populations with the increased participation of old generative individuals. The cenopopulations of these types include those in steppes with dominance of Elytrigia nodosa, polydominant steppes and shrub associations, where favourable age group correlation combines with the high quantity of Rosa canina. The connection of dog-rose with the secondary associations allows to extra

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# Maritime engineering during the Roman Republic and the early empire

**J.M.E. Prada and J.M.O. De la Peña**

*Centro de Estudios de Puertos y Costas, Cedex-Moptma, Calle Antonio López, Madrid, Spain*

## 1. ABSTRACT

The paper briefly describes the wealth of knowledge concerning maritime engineering achieved by the Roman *curatores* (engineers) up to the period of the Early Empire. This knowledge was obtained because they knew how to bring together all the technologies of previous civilizations. The study contemplates only three aspects of their knowledge and maritime techniques which are not usually studied: the foundation of breakwaters, topography and cartography and marine climate. The sources employed are: literary, archaeological and other complementary works.

## 2. INTRODUCTION

Which technical knowledge had roman civil engineers who work in harbours?. Those maritime engineers who made Ostia harbour, reconstructed the ancient harbour of Carthage or used floating caissons.

Which geotechnic knowledge did they have?, which types of structures or foundations did they build?, how did they make?, etc..

We can ask many questions about the roman technical knowledge and we'll try to answer every questions using the classic literature, archaeologic studies, etc..

## 3. TECHNICAL KNOWLEDGE OF ROMAN ENGINEERS

If we study the classic roman writers -Strabo, Vitruvius, Mela, Pliny, Flavio Josefo, etc.- or archaeologic works about it, we can see roman engineers had a high technical knowledge.

They distinguished between a simple point or bay for arriving ships and a harbour, because they, like us, said harbour when it had different services (Vitruvius 5-XIII); warehouse (*horreas*), porch, shipyard, slipway, etc..

They knew to plan the disposition of harbour breakwaters in plant according to maritime climate -wind, waves, etc.- and for that they needed to study the maritime climate of the place which want to construct the new harbour (Vitruvius 5-XIII, Flavio Josefo 1-XVI).

Before selecting the exacting place for building new breakwater, roman engineering did geotechnic studies, as we can deduct of the classical writers (Vitruvius 5-XIII)., because it depended the type of the bottom, the foundation for breakwater. In order to do geotechnic studies they used divers (*urinatores*)(Quinto C. Rufo) and sounding machines.

Roman civil engineering had a high development when it was discover the concrete, using puzolanic concrete, known as *carbunculo*, which was, firstly, taken in the region of Cumas and Bayas (Vitruvius 2-VI).

## 4. TYPES OF BREAKWATERS

We can study the type of breakwaters during the roman republic and the early empire using archaeologic works or the description ones which made classical roman writers as Vitruvius.

Vitruvius, in his book "The nine books of architecture", has a chapter dedicate to maritime works (Vitruvius 5-XIII), and according to him, the following types of breakwaters existed in that period:

a) Vertical breakwater
b) Piled breakwater
c) Rock breakwater

The vertical breakwaters could be built with natural rocks or concrete blocks finished off in different ways, or with concrete. Normally, this type of maritime structure was used as breakwater and wharf.

The piled roman structures known up nowadays were only interior structures. A well known example is the pier painted in the famous fresco of Pompey which represent the harbour of Puteoli, *figure n° 1*.



The rock breakwaters could be of the Hellene type, with a wave wall, with a damping basin, etc.

When the draught were very high, they used a type of combinated breakwater; from bottom till 6 or 7 meters they constructed a submerged rubble mound, from 6 or 7 meters to up they constructed vertical breakwater. Finally, they put rocks before vertical breakwater, example of this type of breakwater is in the harbour of Cesarea Maritime, *figure n° 2*.

After death Vitruvius, it was very extended the construction of breakwaters with arches, as we can see in the harbours of Ostia and Puteoli, *figure n° 1*.

## 5. FOUNDATION METHODS AND BREAKWATER CONSTRUCTION

The roman civil engineers had a knowledge of geotechnics. According to the type of foundation soil, they used a rubble mound foundation, drove piles into the ground, employed in-situ underwater concreting, dry cofferdams, concrete block sections, etc..

When the quality of the bottom was enough good, they only dredged a superficial layer and built up or constructed a bedding rock layer. When the draught were 6 or 7 meters up, they constructed a submerged rubble mound, as we have said before, *figure n° 3b*.

If the bottom was sand, then they made a long trench with a width longer than wall of breakwater wide, normally double wide, *figure n° 9*. When the bottom was mud and the layer was very high and it was impossible dredging, then Vitruvius (5-XIII, 3-IV) said how they had to prepare the foundation of the breakwater; it must make a land of little piles using wood of olive tree, black poplar or holm-oak with scorched points, and between the heads of piles it must put coal rocks.

We can classified the breakwater construction the following types:

**a) Vertical breakwater-wharf of massive concrete**:

The steps for constructing this type of breakwater is described in Vitruvius (5-XIII) and is fully explained in our work about Vitruvius, see references. Firstly it was made a sheet pile cofferdam with iron corners in order to put a chain around it, *figures n° 3a and 4*.

Then the bottom was dredged with manual dredge like it had been used till last century, *figure n° 3b*. When the bottom was cleaned, concrete was put in the interior of the cofferdam under the water till fulled it, *figure n° 3c*.

Finally, it was built a external walls with blocks and was put mooring berth, *doctyliums*, see *figure n° 5*. The width of this type of structures was about 21 feet or 6 meters. This type of breakwater was constructed in protected water where the wave height was very low.

**b) Vertical breakwater-wharf of concrete blocks:**

As said Vitruvius (5-XIII), this type of breakwater was appropriated for waters with waves and wasn't able make a sheet pile cofferdam like first type.

Work was beginning from shoreland; making a bedding rock layer like submerged rubble mound, following land slope, till 2 or 3 meters depth, *figures n° 6a and 7a*. Then head submerged rubble mound was built horizontal, till 4 or 6 meters depth, *figures n° 6b and 7b*.

When the submerged rubble mound was constructed, it was made a sheet pile of 46 centimeters wide around it and then the cofferdam was fulled with sand. A block of concrete was made on it. Its size was, approximately, 2 or 3 meters wide an high, and 10 or 15 meters long.

When the concrete block was finished, little doors down the cofferdam were opened and water came into and moved sand outside the cofferdam, and blocks got down till they were put on the rubble mound, *figures n° 6c and 7c*.

When the vertical breakwater got more than 6 or 7 meters depth, it was very difficult and complicate to make sheet pile cofferdam. Then they changed that construction method and instead it used wood floating caissons and the rest of construction was similar.

The best example, well known, is the breakwater of Cesarea Maritime, made by Herod the Great, and was well described by Flavio Josefo (1-XVI) and by many modern archaeologic studies and reconstructed its cross section by us, *figure n° 2*[1].

**c) Vertical breakwater-wharf of rock blocks wall:**

This type of breakwaters was appropriated for seas with waves and when it was impossible getting concrete, or Puzol powder, according to Vitruvius (5-XIII).

[1]The difference between the method described before and the method which appear in the figure n° 2 is the position of concrete block, perpendicular or parallel to the breakwater cross section.



The construction started from shoreland. Firstly, it was constructed a cofferdam with two sheet pile, separated 1 roman step (1,487 meters), filled up with clay bag, like they used for making piles of big bridges, *figure n° 8*. Secondly, they emptied out the cofferdam with water bombs, *cocleas*, and put transversa woods in order to hold hydrostatic pressure.

When the cofferdam was dried, they started to construct the foundation, but it depended on type of ground. If ground was good for constructing on it, it was made a long trench twice wider than future wall, *figure n° 9*, and it was filled up with poor concrete.

When ground of bottom was bad, mud for example, it was made, as we have written before, a land of a little piles using wood of olive tree, black poplar or holm-oak with scorched points, and between the heads of piles it must put coal rocks, Vitruvius (5-XIII, 3-IV).

When the foundation was finished, it was constructed two structure exterior walls with rock blocks and between them it was emptied out with sand, gravel, cobble etc, material with no classified grain. Finally the head of the breakwater was made as a way, using rocks, stones, etc.

## 6. AUXILIARY TOPOGRAPHIC AND CARTOGRAPHIC ELEMENTS

Making and drawing maps, plans, etc. is quite antique; the first documents more antique better known at the present time are some maps in terra-cotta from Mesopotamia. Drawing maps in ancient Egypt was very extended, the same as minoan people, as you can see in the frescoes of Acrotera, Santorini.

We have very few antique maps but we don't know exactly auxiliary topographic elements they used in order to make those maps. Topography and cartography had the same importance in roman period as at the present time, Polibio (3-IX, 34-VI).

The first Mundi Map that we know was made by Anaximadro from Mileto at the beginning of VI century b.C.. Later, Hecateo from Mileto, between VI and V century b.C., and Dicearco from Mesina, at the end of IV century b.C., Polibio (34-VI), introduced many modified, introducing references lines. In the next century, Eratostenes from Cirene, Polibio (34-VI), drew a new Mundi Map with parallels and meridians. Every classic literature have many references about geography data and geographers, but they are especially interesting in Strabo, Pliny, Mela and Polibio.

Roman people left, mostly, cosmography and mathematic-geographic studies, and developed topography and cartography more practical; making maps in the country using topographic instruments, as *gromaticos*, who were a corp of surveyors that used an instrument called *groma*, or *libratores*, topographer.

The antique literary sources more important with geographic, topographic and cartographic references are the following: 1st *Avieno and the periples*; 2nd *Polibio*; 3rd *Strabo*; 4th *Mela*; 5th *Pliny*; 6th *Ptolomeo*; 7th *The itinerary*.

Nautical chard or coastal maps existed and had from ancient times, as we can read in Herodoto (3-CXXXVI): *"...Abastecidos de todo, siguieron rumbo a Grecia. Al costearla, contemplaban las costas y levantaban planos, hasta que tras contemplar la mayor de sus lugares..."*[2].

The type of maps which might exist in the roman period we can classified in:

1st *Mundi Map and maps of large areas*: The most famous of these type of maps was the *Orbis Pictus* of Agrippa, which was the most complete map of the known world and it was painted in the Vipsalinia Polla Portic in Roma. It was planed by Julius Caesar and made by Augustus with his son-in-law Agrippa, as it was said by Pliny (3-XVII).

2nd *Portulanos and nautical charts*: It was demonstrated that it existed nautical charts, as we can read, and we've written before, in Herodoto. It is quite probable that there were maps with interest coastal points and ports, called in the Middle Age as Portulano, but this point is a simple hypothesis.

3rd *Periples*: The periples were a writing of coastal description which were done by sailors in their travellers.There are many famous periples as: Scylax, Hanno, Piteas, etc..

4th *Lineal maps of land and maritime fairways*: This type of maps were descriptives of some ways and only useful topographic elements for travellers were drawn in they, for that, this type of maps were mainly practical and easy to understand, example of this type of maps were the *Itineraria Scripta*, which were like modern tourist guide, and the *Itineraria Picta*, similar to a modern road-map book. The only map that we know and exit at the moment is the Peutinger Map or *Tabula Peutingeriana, figure nº 10*, which is a copy of X century a.C., 6 meters long and 34 centimeters wide, from an original of IV century b.C.. Other type of important itineraries existed in that period, for

[2]We prefer no translated from our spanish work because we could have many mistakes. We are sorry for that.



example; the *Itinerariun Antonianum*, which was written about 300 years a.C. and a copy of VIII century a.C. is in El Escorial (Madrid).

5th *Maps of a little areas*: It may be many of this type of maps which, unfortunately, we don't have nowadays an example of those but only in some frescoes and mosaics without topographic value.

6th *Design and construction plans*: We haven't found any document which said specifically that they existed, we can deduce, if we read technical documents (books, letters, etc.), that roman engineer, *libratores* and *gromaticos* drew plans of construction before beginning a work. Example of that is the paragraph of a letter that Pliny sent to Trajan: "... *Now it concern you, if you think correct, sending a topographer or a engineer in order to determinate, with careful studies ...* "[3]

It was made projects for big public works, and including in it geotechnic and topographic studies, as we can deduce from many documents. It's possible that corps of military topographer and engineers existed in that period.

They are most unknown the type of topographic instruments than maps. We only know a little bit part of instruments but not all and its evolution. The roman topographic instruments we know today are:

*Dioptra*: It was the main roman topographic instrument, it was like the nowadays level, but it didn't have optic elements, for that it can't use for long distances. This instrument have been studied for many historian and exist many references in classic books as Polibio (3-XV).

*Levelling*: It was an auxiliary instrument of dioptra, similar to actual one. The working method was the same to today method; librator saw ahead and back with dioptra and compared both data.

*Chorobates*: Or levelling table, it was used for precision levelling, for example channels. It was a long wood table with a water level in the middle one and four scourge with lead balls near of legs.

*Groma*: It was the instrument of surveyors or *gromaticos*. It was put horizontal on the ground, using four scourge with lead balls which have in its arms and you could see along the arms.

[3]This paragraph has been translated from spanish, and it said: "*...Ahora os corresponde, si lo creis adecuado, enviar un topógrafo o un ingeniero para que determine, con estudios cuidadosos ...*"

*Tape measurers*: Today is unknown any antique topographic instrument in order to measure distances, but it's not impossible that instrument had existed in the past. Roman topographer used tape measurers in order to measure distances.

*Sounding lines*: Ships had a rope with a weight in order to measure depths. This rope could be calibrated with knots, rings, etc. or they measured in braces.

## 7. KNOWLEDGE CONCERNING THE SEA

Information has come to the present day about the existence of specific books dedicated to this topic, including the construction of ports, although they have not been preserved, but it was known by other authors which had technical books of sea and harbours as Filon of Bizancio or Timostenes of Rhode.

The knowledge about the marine climate of that era has reached the present by non-scientific literary references. Waves, currents, winds and tides are made reference to by the different classical writers, with a particularly in depth explanation of the origin of the tides by Strabo (III-5,8) which he took from Poseidonio and he, in turn, from the Tartessus. And we can find more explanation about tide in Mela (3-I).

They knew that wave tide was a composition of three armonic waves; by day, mount and year, and it depended mainly on the Moon position and relative position of Sun and Moon.

They knew that waves was generated by wind, as we can read in Polibio (11-XII) or in Flavio Josefo (1-XVI), but we don't know if they could study it theoretically although we know they studied the maritime climate of a shore point that they wanted to construct a harbour as it demonstrated the situation of some breakwater studied.

Wind had been studied and known from ancient times due to it was very important in order to sail. They distinguished winds for its directions, and the principal wind direction was very important for designing mouth of harbour, Flavio Josefo (1-XVI).

Lastly, we can a little references about currents and their knowledge in the roman period. Its well known that from ancient times general currents and wind currents were mostly used by sailors, Polibio (4-XIV). Rip currents and undertow was known, too.



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## 9. FIGURES

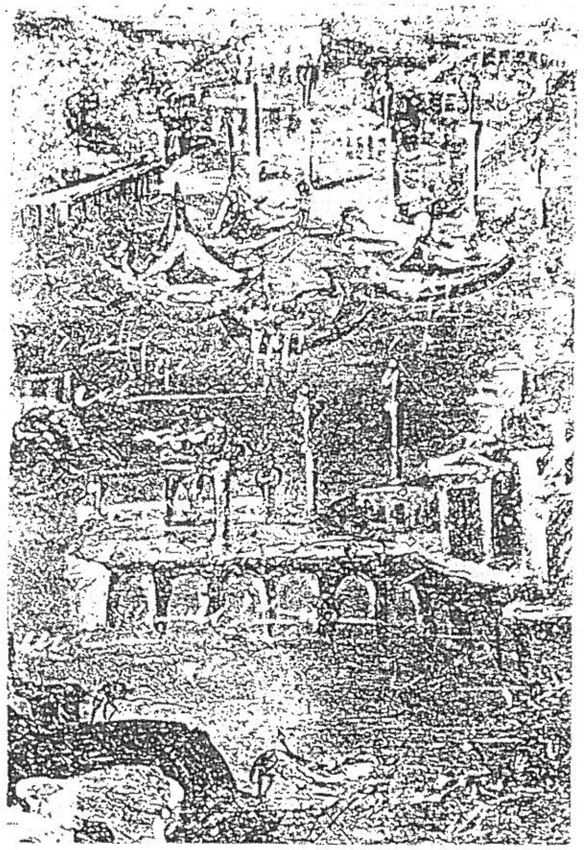

*FIGURE N° 1: Harbour of Puteoli (fresco of Pompey)*



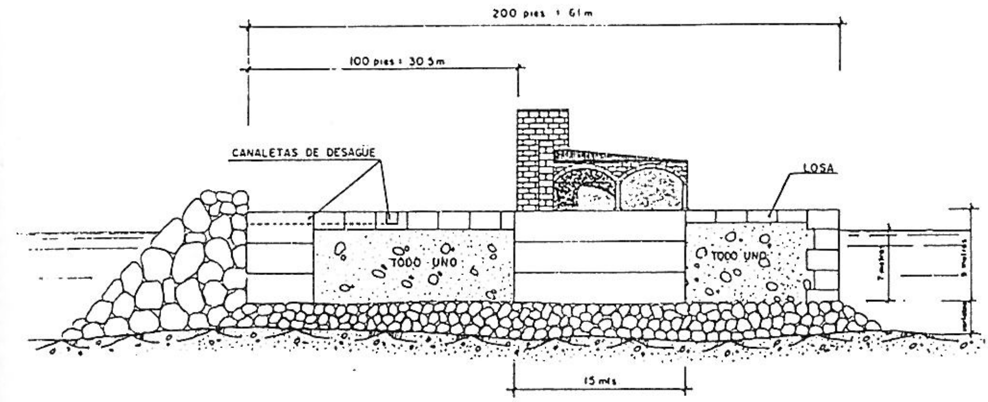


*FIGURE N° 2: Cross-section of Cesarea Maritime breakwater*
*(reconstruction by de la Peña,Prada&Redondo'95, according to Flavio Josefo (1-16))*

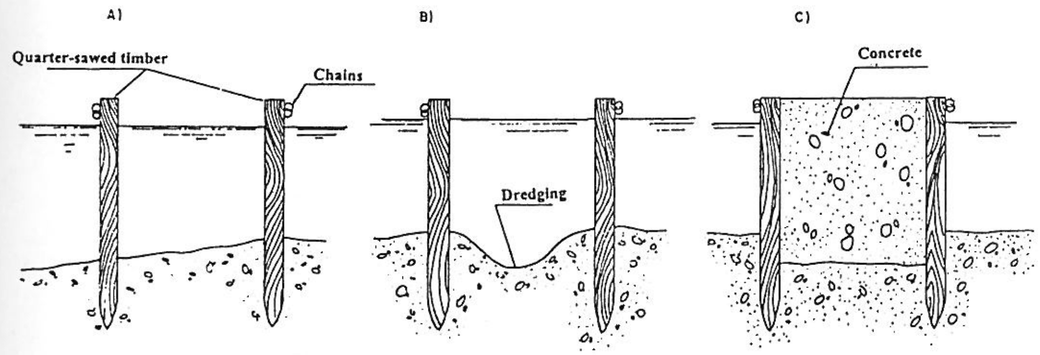


*FIGURE N° 3: Construction steps for masive concrete vertical breakwater (de la Peña,Prada&Redondo'95, according to Vitruvio (5-13))*

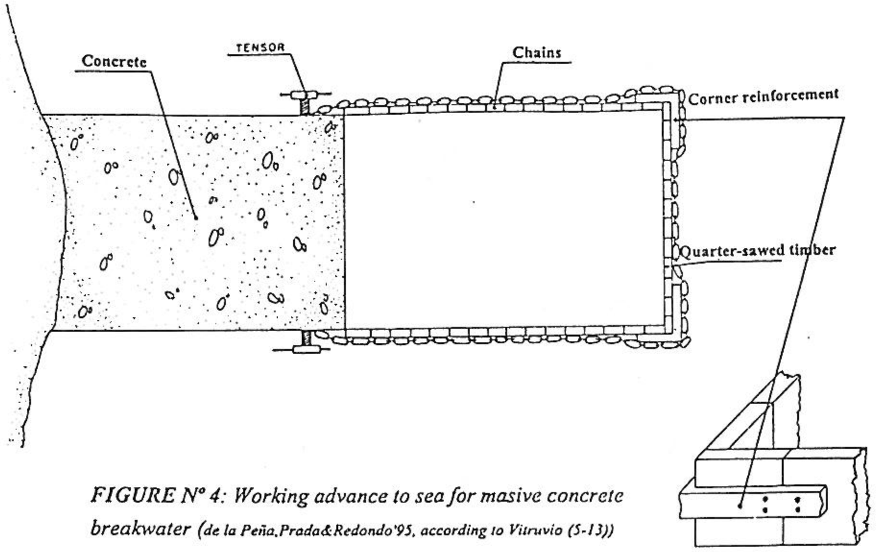


*FIGURE Nº 4: Working advance to sea for masive concrete breakwater* (de la Peña, Prada&Redondo'95, according to Vitruvio (5-13))

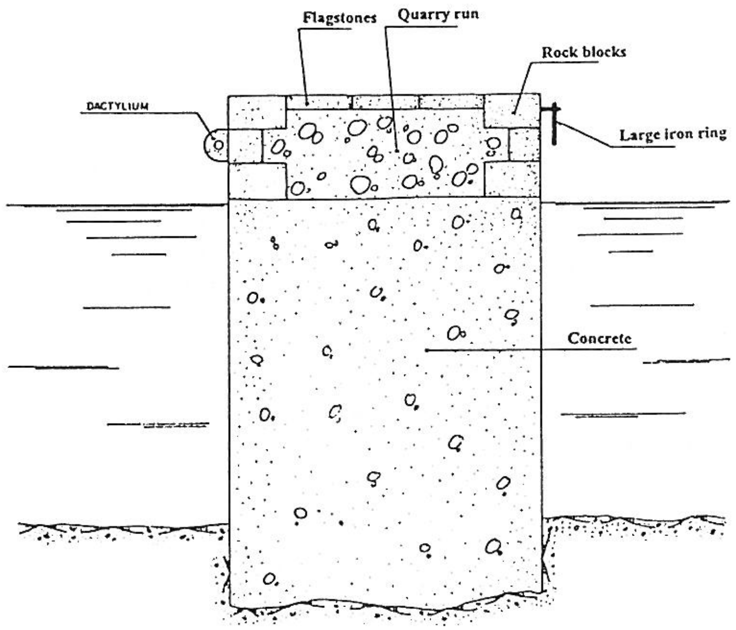


*FIGURE Nº 5: Cross-section of masive concrete vertical breakwater* (de la Peña, Prada&Redondo'95, according to Vitruvio (5-13))

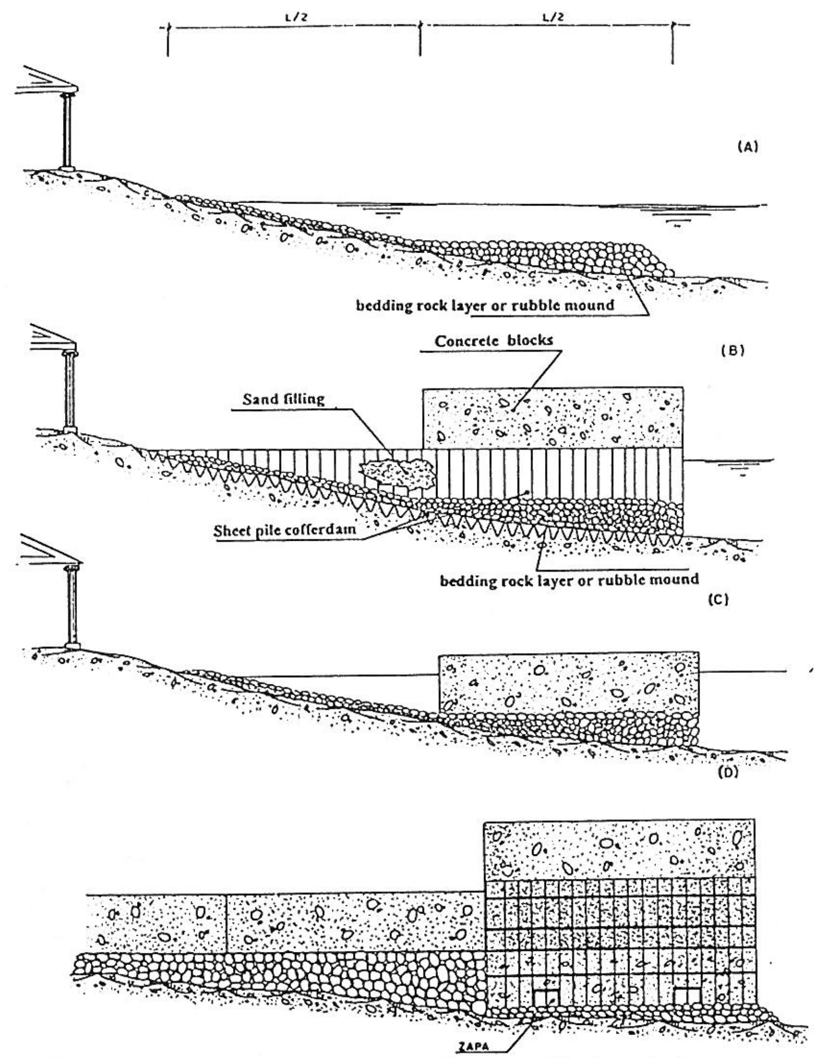


*FIGURE Nº 6: Construction steps for concrete blocks vertical breakwater* (de la Peña, Prada&Redondo'95, according to Vitruvio (5-13))

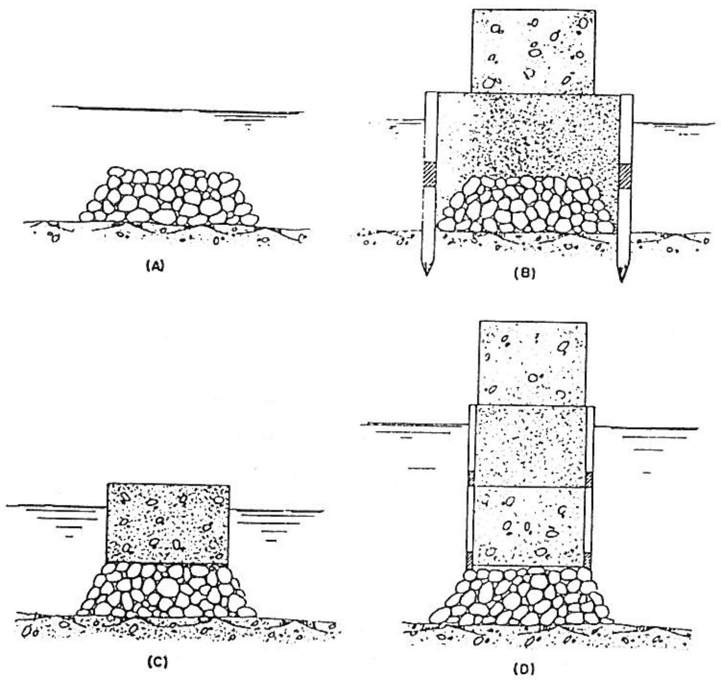


*FIGURE N° 7: Cross-section of different construction steps for concrete blocks vertical breakwater (de la Peña, Prada&Redondo'95, according to Vitruvio (5-13))*

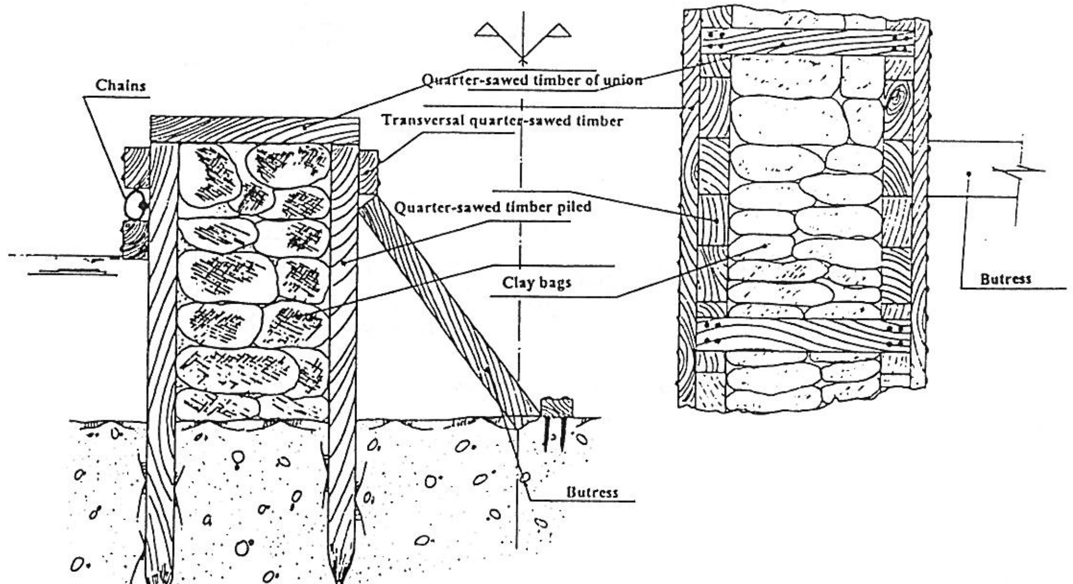


*FIGURE N° 8: Detail and cross-section of cofferdam wall (de la Peña, Prada&Redondo'95, according to Vitruvio (5-13))*



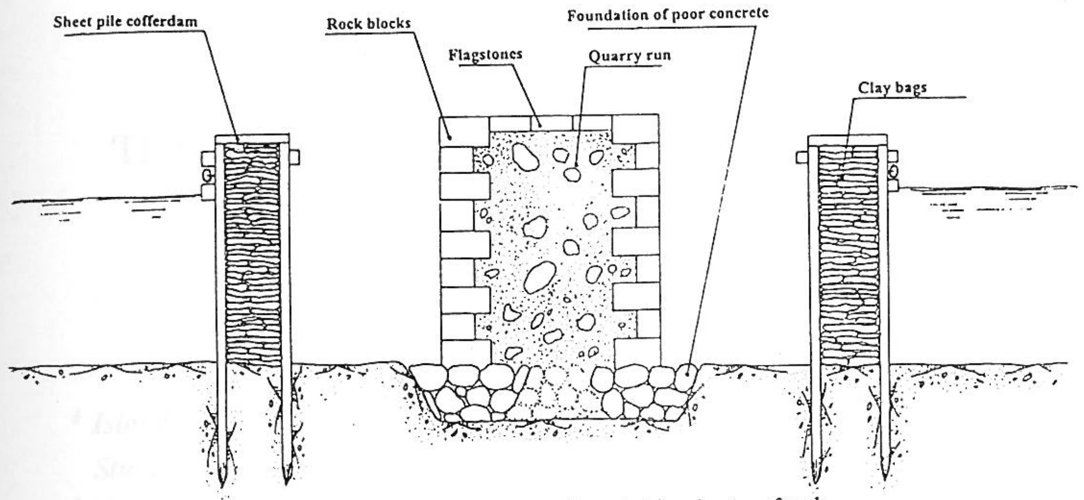


*FIGURE N° 9: Cross-section of vertical breakwater of rock blocks wall when ground bottom was good (de la Peña, Prada&Redondo'95, according to Vitruvio (5-13))*

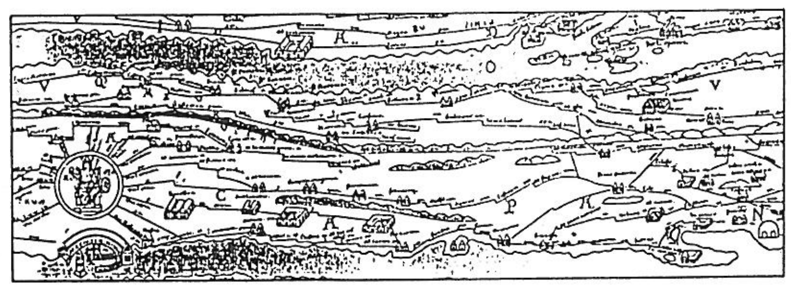

*FIGURE N° 10: Detail of Peutinger Map, on the left you can see the Ostia harbour*